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PART II—PRESIDENTIAL ADDRESSES

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Presidential Address

(Delivered on Jan. 2, 1941)

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SCIENCE AND INDUSTRY.

I feel that the authorities of the Indian Science Congress Association have made a very bold departure in electing a layman to the honour of the Presidentship for the year and, deeply conscious as I am of the honour, I confess to a feeling of diffidence in occupying a post which has been adorned by so many distinguished scientists before me. If my address falls short of the standard set by my predecessors, the responsibility of it should in part be borne by those who have elected me. The only reason for their choice, as far as I can see, lies in the fact that I may lay some claims to be an industrialist. So close and intimate is the relationship between science and industry and so strongly is that fact being brought home to us in these days that the Association felt perhaps that they would like to have the views of an industrialist on the relationship of science to industry with particular reference to the practical problems which have arisen in India since the beginning of the war. A substantial part of the export trade of India has been lost since the war. Science can help in the utilization within the country itself of some of the raw materials which used to be exported. Researches are being conducted for instance on the use in India for lubrication purposes of some of the oil seeds of which the export has dwindled down and the surplus of which is likely to create serious economic trouble for the cultivator. Even a more acute problem is the stoppage of the import of many commodities essential for the economic life of the country, such as machinery, chemicals, etc. It is imperative that India should make herself self-sufficient with regard to such materials as are vital to the maintenance of her economic and industrial life so that the situation which had arisen during the last war and which has arisen once again may never recur. It is here that science can be of the greatest assistance to industry. Research has been described as the mother of industry and while some of the older and more traditional industries may have originated without the aid of science, it

Value of Research in Industry.

cannot be denied that all industries to-day depend upon science and research not only for their progress and improvement but also for their survival. Sad experience has proved to us beyond all doubt that, under modern conditions, no nation, however peacefully inclined, can expect even to live an independent existence unless it is highly industrialized. It is the industrial potential that is convertible into the war potential and the country that has the highest industrial potential and is prepared to convert it in the shortest time into war potential that stands the best chance in modern warfare. As we have seen, it is not man power that counts in the highly mechanized warfare of the present day, but planes, tanks, guns, ships and the factories, plants and workshops behind them. The lesson for India is plain and she can only neglect it at her peril. It is no longer the question of a balanced economy or of mere material progress. It is necessary for India's very existence that she should be highly industrialized.

This lesson was first taught during the last world war. Owing to its superior scientific organization and equipment Germany was able to withstand the Allies much longer than she could otherwise have done. At the beginning of that war, England found that she was deficient in many forms of optical glasses, dyestuffs, chemicals and other necessities for the conduct of modern warfare. She set herself to remedy these drawbacks. A very important dye industry was created and the whole of the scientific and research talent of the country was organized by the creation of the Department of Scientific and Industrial Research. It is not necessary for me to enter into the details of the organization and working of the D.S.I.R. with which many of you must be familiar. An interesting feature of the organization, however, to which the attention of the authorities in India needs to be drawn is that the administrative organization of the D.S.I.R. is entirely composed of technical men, while the Advisory Council, which guides and controls its activities, is mainly composed of distinguished scientists with the addition of two or three well-known industrialists and business men. The words of Lord Rutherford to the Twenty-fifth Indian Science Congress, though frequently quoted since then, will bear repetition as they have an important bearing on the policy of the Government of India towards the recently created Board of Scientific and Industrial Research. He said:

'In Great Britain, the responsibility for planning the programmes of research, even when the cost is borne directly by the Government, rests with research councils or committees who are not themselves State servants but distinguished representatives of pure science and industry. It is to be hoped that if any comparable organization is developed in India, there will be a proper representation of scientific men from the universities and corresponding institutions and also of the industries directly concerned. It is of the highest importance that the detailed planning

of research should be left entirely in the hands of those who have the requisite specialized knowledge of the problems which require attack. In the British organizations there is no political atmosphere, but of course the responsibility for allocating the necessary funds ultimately rests with the Government.'

There has been a tendency in the past in India for scientific and research work to be monopolized by Government Departments and although valuable results have been obtained, e.g., by the Survey of India, the Geological Survey, the Botanical Survey and in the investigation of tropical diseases, it is very necessary that organized industrial research should as far as possible be left to scientists and industrialists although of course Government has to see that the grants it makes are properly utilized.

Board of Scientific and Industrial Research.

Industrial research was organized on a country-wide basis in America as well as in several countries of the British Empire following the lessons of the last war. In India also the war revealed the helplessness of the country. The transport service was disorganized owing to lack of railway material; supplies of dyes, important chemicals and many important medicines were almost completely stopped and prices of textiles shot up so high as to be beyond the means of poor people. In 1915 the Government of India addressed the Secretary of State as follows:—

'After the war India will consider herself entitled to demand the utmost help which the Government can afford to enable her to take a place, so far as circumstances permit, as a manufacturing country.'

This policy was accepted by the Secretary of State and the Indian Industrial Commission, under the Chairmanship of Sir Thomas Holland, was set up as a result. Unfortunately, however, the impetus to industrialization provided by the war died down after a few years and many of the industries which were started during the war languished and died. The gathering storm clouds of a new world war drew the attention of Indian scientists to the unorganized state of scientific and industrial research in India and repeated appeals were made for the constitution of a body on the model of the D.S.I.R. The urgent need for the appointment of such a body was voiced by Professor J. C. Ghosh in his presidential address to the Association at Lahore in 1939 and was reiterated in a resolution of this body last year at Madras. The same point was made by Colonel Chopra in his presidential address to the National Institute of Sciences in Madras last year and by Sir M. Visvesvaraya in an address to the Indian Institute of Science, Bangalore. We, therefore, cordially welcome the recent appointment of the Board of Scientific and Industrial Research by the Government of India in response to the demand of scientists throughout the country. Our thanks are due to the present Commerce Member,

Sir Ramaswami Mudaliar, who lost very little time in appreciating the urgency of the constitution of such a body under the conditions created by the war.

I am a member of the Board and keenly interested in its success. Any observations which I may make upon it are made in a purely constructive spirit with the object of enhancing its utility to the country. In the first place then, I may be permitted to say that although the beginning of the Board, like most beginnings, may be small, its conception must be large and liberal. It must not, in its composition or working, bear the appearance of a mere ad hoc body created to meet the immediate exigencies of the war. The demands of the war are no doubt urgent and must have priority over other demands, but the Board should function as a body charged with the organization and promotion of industrial research throughout the country, and co-ordinate the immediate needs of the war with the long range policy of the industrial development of the country as a whole. While concentrating on what is immediately required to meet war needs, it must also be in a position to survey the long term industrial requirements of the country and to plan a programme of research to meet them. Perhaps after the urgent demands of the war are over, its composition can be enlarged and made more representative of the Universities, Government scientific services, the non-official scientific bodies and the industrialists of India so as to enable it to pursue its ultimate plan and policy.

No institution, however well conceived and designed, can flourish except in suitable political atmosphere and conditions. It was the unfortunate experience of the last war that industries created under the stress of the war languished and died in the post-war period for want of encouragement and protection from Government. The activities of the Board will not lead to the creation of new industries unless industrialists are assured of reasonable protection from Government in the post-war period, when foreign competition will be keen.

I have already quoted the words of Lord Rutherford as a warning against excessive Government control. The progress hitherto made by the Board is not as rapid as we would have wished in war time. This is partly due to the constitution of the Board under which executive authority is concentrated in a central department of Government and partly to the inadequate staff provided for the very urgent and important work that has to be done. There is one other aspect on which I desire to touch and that is the financial. Even for a beginning, a grant of Rupees five lakhs is inadequate and shows to my mind an inadequate conception of the magnitude of the tasks involved. Associated with the Department of Scientific and Industrial Research in Great Britain are the great National Physical Laboratory at Teddington and important Boards, such as the

Fuel Research Board, the Food Investigation Board, the Forest Products and Building Research Institutes and a number of similar bodies as well as Research Associations. While we must necessarily make a very modest beginning, the development of the Alipore Test House into a National Physical and Chemical Laboratory seems tó be obviously and urgently required. In a subsequent part of this address I shall dwell upon the necessities of a Fuel Research Board to investigate the very pressing problems of fuel and power, upon which the whole industrial structure of the country has to be based. All this work will require large funds but I have not the slighest doubt that the money so spent will be repaid manifold. It has been estimated that the annual expenditure on research in Great Britain in normal times before the war was roughly six million pounds, of which one-half was spent on research directed to industrial needs, including the money spent by Government, University Departments and private firms. The figure for the U.S.A. is estimated to be 300 million dollars, while the corresponding figure of the U.S.S.R. is reported to be of the nature of 120 billion roubles. With the exception of the U.S.A. and the U.S.S.R., there is no country in the world with natural resources so vast and varied as India. With the expenditure of even a fraction of the amount spent by the countries just mentioned on industrial research, these resources can be investigated and developed so as to place India in the front rank of the industrial countries of the world.

The Steel Industry in India.

I propose now in the second part of my address to speak to you on some developments in the steel industry in India during the last ten years; but before doing so I should like to make a few remarks on the raw materials which are commonly used in the manufacture of iron, namely, iron ore, coal and limestone, and particularly coal, which is the most important of our raw materials and of the most general interest.

Iron ore.

So far as iron ore is concerned, India is one of the richest countries in the world, being endowed by nature with very extensive deposits of very rich ore. The Singhbhum-Orissa field is the most extensive in India. The tonnage of this field has been estimated by Mr. H. C. Jones of the Geological Survey, at 3,000 millions, and, if anything, it is probably an underestimate. Practically the whole of this ore is hematite, with an iron content of sixty to sixty-nine per cent.

Coal.

While the position regarding iron ore is highly satisfactory, that regarding coal, particularly the coal required for the smelting of the iron ore, is far from satisfactory. Dr. Fox has estimated the resources of Indian coal over four feet in thickness up to 2,000 feet in depth and twenty per cent in ash at 24,000 million tons, of which coal of good quality up to

18% ash is 6,000 million tons, while coking coal suitable for metallurgical purposes is only 1,400 million tons. Coking coal in India is confined to the Gondwana coal beds of the Damodar Basin. On the existing methods of working coal the total life of the coking coals of India is estimated at about fifty years. This is a position which neither the Government nor those interested in the metallurgical industry can view with equanimity. The most recent Committee appointed by the Government of India to investigate the position and suggest remedies was the Burrows Committee of 1937. The terms of reference to that Committee were unfortunately not comprehensive enough and the legislative measures taken by Government as a result of the recommendations of the Committee are mainly confined to the ensuring of safety in Mines. The problem of Indian coking coals is, however, one of conservation as well as of safety and if proper attention is paid to conservation, the problem of safety will more or less automatically be solved. Legislation in the interest of safety which places additional burdens on the industry without assisting it to dispose of its production in a more scientific manner, is likely to worsen the situation by hastening the uneconomic exploitation of the good coals by the smaller colliery owners. What is required is the rationalization of production as well as of consumption. In order to achieve the rationalization of consumption, a thorough chemical and physical survey of the coalfields beginning with the Jheria coalfield, in conjunction with a scheme of coal utilization research is absolutely necessary. For that purpose it is necessary to create a Fuel Research Board as a branch of the Board of Scientific and Industrial Research with a proper personnel, adequate staff and funds. Power is a *sine qua non* of the development of all industries and the proper conservation and utilization of the coal resources of the country is the first question that requires to be tackled in any consideration of the power resources of the country. The geological survey of the various coalfields has been excellently and exhaustively carried out at great expense to Government and it is high time that a scientific, chemical and physical survey were also carried out. Such a survey has been instituted in Great Britain and has resulted in a mass of most valuable information regarding British coals which has in many instances completely altered the attitude of the industry to many varieties of coal and enabled a more efficient use to be made of them.

Fuel Research Board.

On the production side the most important problem is that of the co-ordinated sequence of working the coal seams. Perhaps the worst feature of the working of Indian collieries is the exploitation of the richer coal from the lower seams for immediate profit and the neglect of the upper seams resulting in subsidences, fires and destruction of valuable coals. The co-ordinated

sequence of working will prevent this destruction of top seams and will eliminate to a large extent the necessity of stowing altogether. No. 16 seam in the Jheria coalfield is a case in point. This coal has good coking properties but because of its high ash content and doubtful swelling tendencies it has been comparatively unexploited, either as a steam or coking coal.

The washing of coals is another question affecting production. In many cases the ash in the Jheria coals is inherent or when present in a free condition is of about the same specific gravity as the coal itself, thus making the separation impossible or difficult, but it has been proved that in certain of our high ash seams the ash content can be reduced by liquid flotation. 11 and 16 seams Jheria come into this category and further research is necessary to determine whether it is economically feasible to wash these coals with a view to reduce their ash content.

On the consumption side, the chemical and physical survey into our coal seams in conjunction with coal utilization research will in the first place enable us to determine the range and variety of coals suitable for coking as well as boiler purposes. Research is necessary in order to ascertain whether with proper blending and mixing the demands of the metallurgical industry need be confined to the very limited Jheria field. Several experiments have been carried out in the past, but further systematic research by the Board suggested above into blending with high ash coking coals, with swelling coking coals and with non-coking coals may result in the conservation of good coals and an extension of the range of coals available for metallurgical purposes.

Similar research is also required in the case of power coals. A certain amount of information is already available but is mainly confined to the mixing of the high volatile coal in the Raneegunge field with the low volatile coal in the Jheria field for the export market and bunkering only. These low volatile coals from the Jheria are good metallurgical coals and research will doubtless produce suitable blends for export and power requirements without encroachment on these valuable low volatile coking coals.

The utilization of high ash coals for electrical generation at the sources of production and the distribution of the energy thus supplied over large areas is another problem of the first magnitude. The erection of a large power station on the coalfields for the distribution of cheap power to surrounding areas has already been advocated from many sources and has engaged the attention of the Government of Bihar. Further investigation of the suitability of the coal for such a purpose will help greatly towards the fulfilment of this very desirable project and should form one of the first objects of enquiry by the proposed Board.

Low temperature carbonization tests with various classes of coal, particularly of high ash, which are unsuitable for metallurgical purposes and also unsuitable on account of high ash content for transport to distant areas for power purposes, should provide another field for the activities of the Board. A number of scientists from the platform of this Congress as well as outside have advocated the cheap production of domestic coke on a mass scale and the utilization of the resultant tar for industrial purposes. The present very small production of soft coke is capable of very great extension if a market can be found for the coke as well as the resultant tar, even if the gases are ignored for the present. The economic difficulties in the way of such a proposal need not be minimized but practical experiments have already been carried out at Patna under the auspices of the Bihar Government and these would seem to indicate that further research may prove successful. Should this prove to be the case, there would be an adequate supply of raw material for the foundation of hydrogenation plants. This may be regarded as a distant aim as such plants have not proved too successful in other countries, but with the cheap Indian coals and the large quantities of tars which would be available from their low temperature carbonization success may be easier of attainment in India than in other countries.

The Board should also investigate the question of the scientific preparation of coal for the market and buying and selling on specification. This would mean the complete abandonment of the existing unscientific system of grading. The seams which were originally graded, have become exhausted or are nearing exhaustion or have deteriorated to such an extent that the classification is in many cases no longer applicable. The disposal of the metalliferous production of the country has long been established on the international basis of scientific specification and it would be equitable to both buyer and seller alike to establish the buying and selling of coal and coke on a similar basis.

If my proposal for the establishment of a Fuel Research Board is approved, I would suggest that as the Jheria coalfield is practically the sole source of our coking coals and is also the centre of the Indian School of Mines, the headquarters of the Board should be situated at Dhanbad and the School of Mines and its laboratories which should be adequately equipped for the purpose, should be utilized for the investigations of the Board.

The Tata Iron and Steel Company: Progress in the last decade.

The last decade has seen a great expansion of the Steel Industry in India, accompanied by improvement in the various

processes and the application of scientific methods of control. You will forgive me if I confine my remarks to the works of the Tata Iron and Steel Company alone, as the steel-making plant at Bhadravati in the Mysore State was put up in 1936 and has an annual capacity of about 20,000 tons only, while the plant of the Steel Corporation of Bengal with an estimated capacity of two hundred to two hundred and fifty thousand tons of finished steel, has begun operation very recently. In terms of tonnage, the progress can be measured by the fact that while the Tata Iron and Steel Company produced 422,000 tons of finished steel in 1929-30, the corresponding production in 1939-40 was 777,000 tons. Ten years ago only thirty per cent of the demand of the country for steel was met by the indigenous industry, whereas in 1939-40 about eighty-four per cent of the demand was so met and the day is not distant when India will be able to supply not only the whole demand of the country except in a few very specialized directions but also to spare some steel for export.

Following the sequence of the manufacturing processes of steel, I begin with the coke ovens, where the coal is converted into coke.

Coke ovens.

Ten years ago we had three batteries of Wilputte Coke Ovens and two batteries of the still older Koppers Coke Ovens which together produced 720,000 tons of coke, 22,300 tons of tar and 6,600 tons of ammonium sulphate. By 1940 all except one of the Wilputte batteries were replaced by three modern batteries of Simon-Carves Coke Ovens containing 54 to 55 ovens in each battery at a cost of Rupees one crore and sixty-five lakhs. These batteries are of the twinflue 'Underjet' type capable of carbonizing 1,300 to 1,500 tons of coal each per working day. Arrangements have been provided for firing the ovens with coke oven gas or with the cheaper blast furnace cleaned gas. Firing the coke ovens with blast furnace gas releases the more valuable coke oven gas for use in steel making furnaces in other parts of the plant. The twinflue construction assures a more uniform heating throughout the length and height of the oven with a resulting uniformity of the coke produced. As stated in the preceding part of the address, all coals do not give good coke and careful investigations have to be carried out in the blending and mixing of different varieties of coal. To this end three large slot bunkers of the capacity of 2,000 tons each have been installed. Coal wagons, as they arrive from the collieries, are taken over to the selected bunkers and unloaded. The coal is then mixed mechanically in the required proportions from the three bunkers and suitable mixed coal is conveyed by mechanical conveyors to the ovens into which it is charged.

The three principal by-products of the coke ovens are coke oven gas, ammonia which is turned into ammonium sulphate and tar. The sulphuric acid for the manufacture of the

ammonium sulphate is made in a recently installed contact process plant producing fifty tons of 100% acid per day.

So far the manufacture of benzol as a by-product of the coke ovens has only been attempted on a very small scale in India. A plant is now nearing completion at Jamshedpur for the manufacture of benzol and toluole for the Government of India. When it comes into operation, it will be of great assistance in the manufacture of high explosives for the ordnance factories. The plant is designed for extracting benzol motor spirit and toluole and is being installed by Messrs. Simon-Carves.

Blast Furnaces.

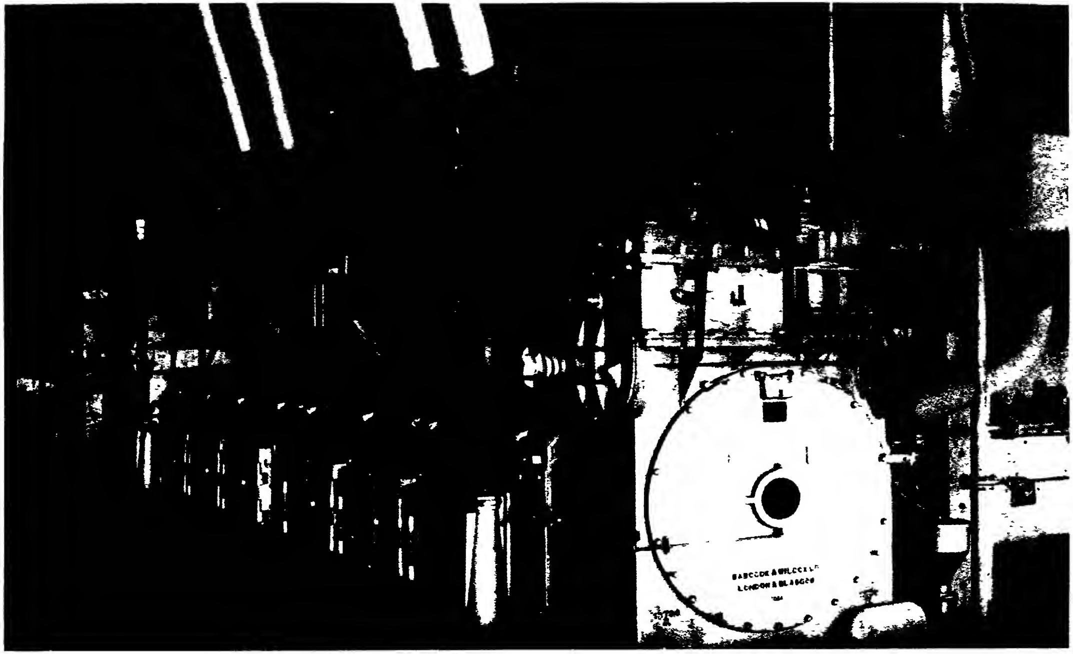
The next stage in the manufacturing process is the blast furnace for the production of pig iron. Ten years ago, Jamshedpur had four blast furnaces; two of the capacity of 900 tons, one of 750 tons and one of 250 tons per day. The small blast furnace was completely rebuilt in 1936 and its capacity was increased to 550 tons. An entirely modern blast furnace was installed last year. The diameter of its hearth is 22 feet 6 inches, of the bosh 26 feet 6 inches and of the top 19 feet. Its height is 95 feet and volume 35,160 cubic feet. For the one year that this furnace has been in operation it is estimated to have produced more iron than has ever been produced elsewhere on a furnace of similar size over a similar period. The total pig iron capacity of the Jamshedpur plant is a million and a quarter tons per annum.

For every ton of iron made, a blast furnace produces roughly 100,000 cubic feet of gas. This blast furnace gas contains about 14 grains of dust per cubic foot of gas at N.T.P. This gas has considerable fuel value, but owing to its dirty condition its use in industrial plants, such as blast furnace stoves and boilers is restricted. It has been realized that considerable fuel economy can be effected if this gas is cleaned. In the last ten years the Steel Company has installed two large gas cleaning plants, each with a capacity of fourteen million cubic feet of blast furnace gas at N.T.P. per hour. Both the plants clean the gas to a purity of 0·008 grains of solids per cubic foot of gas at N.T.P. The older of these two plants is the Lodge Cottrell plant of the dry type which came into operation in 1934. The second gas cleaning plant is of the Brassert design. This plant consists of wooden-hurdle wet washers which not only cool the dirty blast furnace gas but also remove about eighty per cent of the solids from the gas. This semi-cleaned gas is then passed through the Cottrell wet electric precipitators which precipitate the rest of the solids and deliver clean gas to specification.

Fuel Economy.

The old concepts of fuel economy and energy distribution have been completely revolutionized by the modern scientific use of coke oven and blast furnace gases. Fuel economy and distribution of energy in a large plant like that of the Tata Iron and Steel Com-

New Gas Cleaning Plant



New Power Plant

pany is a highly specialized job, which is in charge of a special department of the plant, designated the Energy and Economy Department. The efforts of this department have succeeded in reducing the overall fuel rate from 3·56 tons of coal per ton of steel in 1930-31 to 2·19 tons in 1939-40. Modern practice aims at reducing the use of coal as fuel and replacing it by the more efficient by-product fuels, such as coke oven gas, blast furnace gas, coke dust, etc. The use of mixed gases in this connection requires special mention.

The cleaning of the blast furnace gas permits of its use in coke ovens and releases a corresponding amount of the richer coke oven gas for use elsewhere at the plant. Blast furnace gas has a comparatively low heating value of about 110 B.T.U. per cubic foot of gas, while coke oven gas has a value of about 470 B.T.U. per cubic foot. Modern practice tends to a greater use of coke oven gas or a mixture of coke oven and cleaned blast furnace gas in steel making and re-heating furnaces, replacing to that extent coal which has been used so far in the form of producer gas. Fuel costs are thus greatly reduced. For the successful use of the gases it is necessary to have steady pressure of gas at the consuming ends. For that purpose two large dry gas holders for the storage of blast furnace and coke oven gas respectively have recently been installed. These gas holders act as reservoirs which smooth out the fluctuations of the gas caused by the furnace irregularities and thus assure continuous operation of boilers, coke ovens and other consuming centres. The blast furnace gas holder is a huge structure 283 feet high, 176 feet in diameter, capable of holding 5½ million cubic feet of gas at N.T.P. The coke oven gas holder is 192 feet high, 112 feet in diameter and holds 1½ million cubic feet of coke oven gas.

Steel-making Practice. The last ten years have also seen important developments in steel-making practice and a considerable increase in production.

Steel-making operations at Jamshedpur are carried out in two types of plants, the Open Hearth and the Duplex. The Open Hearth is the oldest part of the Jamshedpur plant. Four out of the seven furnaces which we were working ten years ago, have been remodelled along modern lines and an eighth furnace has been built. The ingot production from this plant has been increased during the last ten years by over 100,000 tons per year, the figure for 1929-30 being 242,000 tons as compared with 345,000 tons in 1939-40. The Duplex steel-making process, as its name implies, consists of two operations, (*a*) blowing the molten pig iron in acid lined Bessemer converters to remove the silicon and manganese and most of the carbon, and (*b*) transferring the blown metal to basic-lined Open Hearth tilting furnaces where the phosphorus is removed and the steel finished to chemical specification. Improvements to this plant during

the last ten years have resulted in increase of production from 340,000 tons in 1929-30 to 670,000 tons in 1939-40. In addition to these two steel-making plants a four-ton electric furnace was installed in 1936 mainly for the manufacture of electric castings, while two five-ton electric furnaces have only recently been installed and are being utilized for the manufacture of class steel, spring steel and alloy steel. The installation of these electric furnaces has been of the greatest assistance in the making of superior quality alloy steel required by the Defence Department.

A New Steel-making Process.

The most important advance made during the last decade, from the point of view of scientific research, is the practical development of the rapid dephosphorizing process. As this matter has never been the subject of public discussion in India so far, a few details will not be out of place here. As is well known, Indian pig iron contains about ·3 to ·4% phosphorus. This percentage of phosphorus in the iron neither lends itself to the straight basic Bessemer process nor to the straight acid Bessemer process. The phosphorus has to be removed to ·05% for most commercial specifications though as much as ·10% is admissible in certain products. The removal of this phosphorus is normally effected by the action of basic and oxidizing slags in Open Hearth furnaces. At the best of times this is a slow operation taking from one to several hours even in the quick working Open Hearth furnaces of our Duplex plant. In 1935, when our General Manager, Mr. Ghandy, and myself were on leave in Europe, our attention was drawn to certain developments in France, where a French Steel Engineer, M. Perrin, had carried out successful experiments in the rapid deoxidation of steel by violent mixing together of slag and steel so as to obtain a considerably greater area of contact between them than could ever be obtained in the conventional Open Hearth furnaces. This idea of the violent mixing of slag and steel was also considered applicable to the dephosphorizing operation. After a study of the French experiments, large-scale investigation over a long period was carried out at Jamshedpur and ultimately a practical method was evolved for operating the dephosphorizing process on a commercial scale under Indian conditions. This new process consists in blowing molten pig iron in an acid Bessemer converter to remove all the silicon and manganese and as much of the carbon as required. This blown metal is then poured from a considerable height into a synthetic molten basic oxidizing slag contained in a ladle. The metal comes into very intimate contact with the slag and the phosphorus is rapidly removed in the course of two or three minutes, instead of as many hours, in the normal open hearth process. As the steel and slag separate, the steel is finished to analysis and cast into ingots.

Bessemer Converters

The process is subject to exact control and steel of basic Bessemer quality can be made directly from the pig iron. Moreover, the dephosphorized metal can be further treated in an Acid Open Hearth furnace and steel of first class open hearth quality can be made. Thus for the first time in India it becomes possible to make acid steel out of Indian basic pig iron. A plant for the manufacture of steel by this process is now under construction. The successful development of this process may be regarded as the most important advance in steel making practice that the young Indian steel industry has made. It is likely to have far-reaching effects on the establishment of several new industries in India, such as locomotive manufacture and the manufacture of railway wheels, tyres and axles, for which acid steel is specified.

Rails.

In the manufacture of rails, advance has been made as a result of metallurgical research during the last ten years. Investigations have shown that medium manganese rails with a lower carbon and higher manganese content of 1·10 to 1·40% have superior properties of wear and resistance as compared to straight carbon rails with higher carbon and lower manganese content. There is a growing tendency to replace straight carbon rails with medium manganese rails. On the other hand, high chromium rails were found unsatisfactory.

An interesting advance has been the installation of Sandberg Ovens for the Sandberg controlled cooling process for rails. All over the world the controlled cooling of rails has come to be looked upon as a definite and desirable advance on the old practice of cooling rails on open hot-beds. The Tata Iron and Steel Company have obtained exclusive rights in India for the working of the Sandberg process. They have installed four Sandberg Ovens for the controlled cooling of their rails. Experiments are also being conducted in the welding of rails in the track. This aims at giving longer lengths in the track between joints and helps to provide a smoother ride.

Plates.

In the Plate Mill, the most interesting development in the last decade is the installation of a modern normalizing furnace for plates. This furnace was first installed to normalize some of the high tensile steel plates for the new Howrah Bridge. By the aid of this furnace it is now possible to produce in India normalized plates which had formerly to be imported. The furnace is also used to normalize certain structural sections. Thus materials with a new range of physical properties have been made available to the designing engineers. It is worth noting that Indian plates have largely replaced foreign plates even for the most exacting demands, such as for barges and ships.

Ten years ago, the Sheet Mill at Jamshedpur consisted of five hand-operated units and the total annual production was

38,000 tons. The rolling of sheets was an extremely strenuous manual operation calling for considerable physical exertion. Production was low, defects and rejections were high. To-day we have only four hand-operated mills and three mechanized units with an output of 170,000 tons. These new mechanized units have produced tonnages which, as far as can be ascertained, constitute a world record for this type of equipment. Besides the ordinary quality mild steel sheets, the Jamshedpur plant now turns out different classes of sheets with a high grade finish, including 'Tiscor' and high carbon sheets. Panel plates for coach building are supplied to the Railways and the various engineering firms. Other special developments in sheet manufacture are the rolling of drum stock for the manufacture of drums and containers, enamelling stock for deep-drawing and subsequent enamelling, furniture stock and, lastly, special sheets for steel helmets for the army.

Sheets.

It is owing to applied research that most of the significant advances in the steel industry at Jamshedpur during the last decade have been made possible. I have already mentioned the case of the rapid dephosphorizing steel. The development of low-alloy steels is another very important instance. Engineers in general and transportation engineers in particular are beginning to realize that ordinary carbon steel performs its functions only at the expense of unnecessary dead weight and excessive loss due to its low resistance to corrosion and abrasion. The problem of providing suitable materials for lighter weight is not one relating to mechanical strength alone. It requires the integration of several properties in one material, such as strength, resistance to impact, corrosion and abrasion, ease of forming, satisfactory welding, etc., as well as moderate cost. With this end in view, metallurgical research was conducted at Jamshedpur, resulting in the development and commercial manufacture of a low alloy, high-tensile steel containing copper and chromium known as 'Tiscrom'. This steel is being employed in the construction of the new Howrah Bridge.

Low-alloy Steels.

The introduction to India of another low-alloy high-tensile steel, sold in America under the trade name 'Corten' deserves mention. Research conducted in America had shown that the addition of a high percentage of silicon and phosphorus to alloy steel, containing chromium and copper, resulted in a low-alloy high-tensile steel of the same properties as those of Tiscrom but with the additional important property that it could be readily welded by all methods of rapid welding such as oxy-acetylene and automatic electric welding. After an investigation into the possibilities of the manufacture of this steel in India and an examination of the claims put forward for it, the Tata Iron and Steel Company obtained exclusive rights for

the manufacture and marketing of this steel in India under the trade name of 'Tiscor'.

Reference has already been made to the installation of the electric furnaces. Among the special qualities of iron and steel manufactured from these furnaces are chrome-manganese steel for crane track wheels, thirteen per cent manganese steel for crusher jaws and similar hard wearing parts of machinery, nickel-chrome heat-resisting steel and cast iron for various castings required to withstand high temperatures and nickel-chrome-molybdenum steel for crane pinions, mill rolls, etc. The manufacture at Jamshedpur of special alloy steel rolls has enabled the Steel Company to replace similar rolls of foreign manufacture.

Special Steels.

Since the outbreak of the war, intensive research work has been undertaken for Government in connection with the manufacture of armoured vehicles in India, and as a result a bullet-proof armour plate of special alloy steel which has stood the firing tests and has been accepted by Government, has been developed. Suitable steels for the manufacture of armour piercing shot and for steel helmets have also been produced. Research work was undertaken at the instance of Government in regard to the supply of steel suitable for telegraph wires. This steel has now been successfully manufactured and the wire rolled at the works of the Indian Steel and Wire Products out of this material has met with the approval of the Department of Posts and Telegraphs.

Researches are being carried out on behalf of the Defence Department in connection with the welding of chrome-molybdenum steel plates for aircraft manufacture and in other directions.

Most of the high speed steel requirements of the plant for machine tools are now being met by the remelting of tool scrap in the high frequency induction furnace in our laboratories. High chrome and stainless steels have been produced in the furnace in small quantities.

Besides metallurgical research, fuel research, chemical research and research in refractories are being pursued. Researches of the fuel department in blending and mixing have resulted in the determination of the most suitable varieties of coals for coking and similar purposes. Research on refractories has enabled us to evolve a better class of refractories for the use of the steel plant. Indian raw magnesite was at one time considered unsuitable for use in basic steel furnaces. Investigations carried out at Jamshedpur have now made it possible to produce in India the Steel Company's entire requirements of finished magnesite. Metal-cased magnesite bricks made at Jamshedpur have given very encouraging results for the superstructure of basic furnaces. Chrome magnesite brick for use above the slag line in basic Open Hearth furnaces in place of

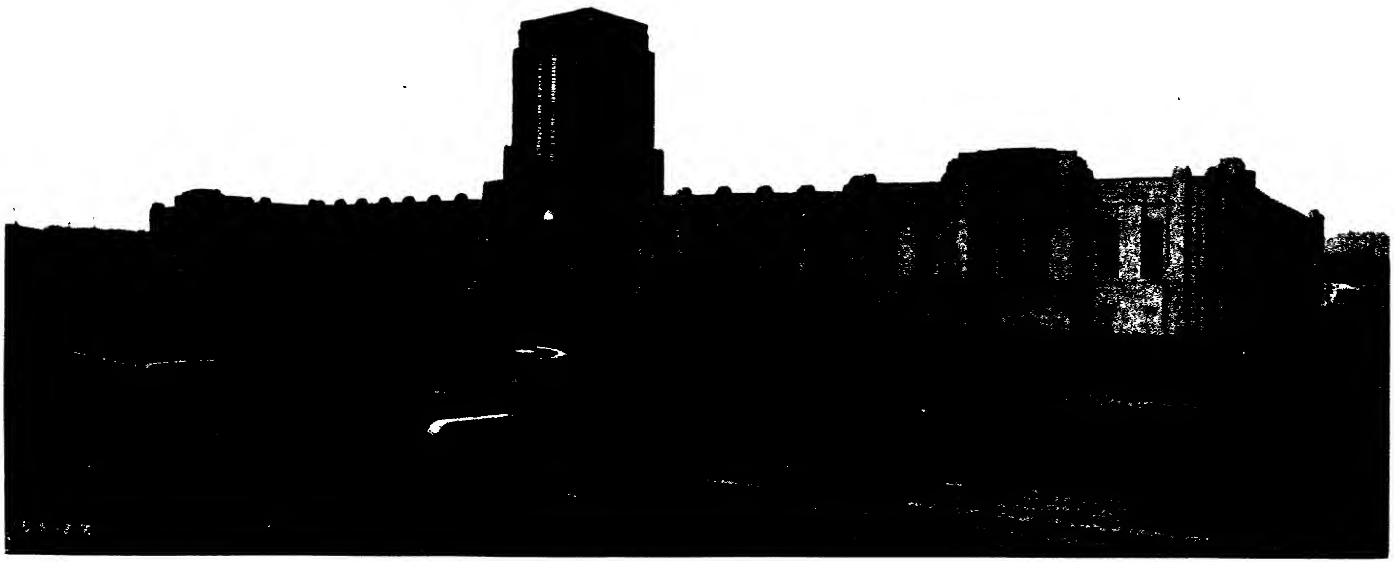
silica brick is another important development in the refractory field. Other interesting developments in brick manufacture are investigations into the possibilities of the manufacture of forsterite, semisilica, micaschist and mullite bricks. An entirely new process has been developed for the manufacture of mullite refractories using cyanite, silimanite and andalusite, India having practically a monopoly of the first two. Very productive work has also been accomplished with regard to high-temperature mortars. Superior types of mortars for high temperature work are now being locally made, replacing many of the imported brands.

To facilitate research work, a modern well-equipped laboratory was erected in 1937 at a cost of over Rupees ten lakhs.

A nucleus for a National Metallurgical Laboratory.

May I express the hope that with the facilities for metallurgical research provided by this laboratory and its workers, Jamshedpur may in the near future become the centre of a National Metallurgical Laboratory and Research Institute and thus be enabled to play a greater and worthier part in the development of the metallurgical industry in India.

When the titanic conflict now being waged ends, as end it must, in the triumph of the democracies and the cause of human freedom, I pray that India may emerge from it with the foundations of its industrial as well as political freedom well and truly laid, so that she may be properly equipped to play her rightful part in peace and in war as a worthy member of this great commonwealth of nations.



New Control and Research Laboratory

SECTION OF MATHEMATICS AND STATISTICS

President :—M. Raziuddin Siddiqi, Ph.D., F.N.I.

Presidential Address

(*Delivered on Jan. 3, 1941*)

FUNCTIONAL ANALYSIS AND MATHEMATICAL PHYSICS

1. Introduction.

During the last 150 years mathematics has not only made an immense advance in the directions already indicated by Descartes, Newton, Leibnitz, Euler and Lagrange, but entirely new branches have been created, such as projective geometry and functions of complex variables in the pure, and mathematical physics in the applied domains. This development in mathematics has often gone hand in hand with the progress of the natural sciences. New methods of attack have been developed in order to solve the problems set by these sciences. The most famous example of this kind is the Fourier analysis developed in connection with the theory of Heat conduction. The recent development in the theories of integral and integro-differential equations owes its origin mainly to the occurrence of such equations in mathematical physics.

At times, however, the trend of events has been in the opposite direction. Many subjects in mathematics were developed purely for their own sake by the generalization of previous concepts. At the time of their creation they were considered to be so abstract as to be of no earthly use for any applications. But as our knowledge of the world advances, even the most abstract branches of mathematics are being found to be required for the explanation of the processes of nature. We have gradually seen the functions of complex variables, functions of an infinite number of variables, tensors, quaternions, matrices and groups become powerful tools in the hands of the physicist.

Mathematics is thus becoming more and more indispensable for all other branches of knowledge. The formulation of all the fundamental laws of nature requires its use. Dirac has recently pointed out that 'Mathematics is the tool specially suited for dealing with abstract concepts of any kind, and there is no limit to its power in this field. For this reason a book on the

new physics, if not purely descriptive of experimental work must be essentially mathematical.'

Another characteristic development of modern times is the rise of the deductive method in applied mathematics. Instead of advancing from particular cases to the general, as done in the inductive or historical method which prevailed up to the 19th century, mathematicians now sought for the most general and comprehensive law from which particular consequences could be deduced as necessity arose. Thus, to give one or two well-known instances, in mechanics instead of starting with Newton's laws and then generalizing them to Lagrange's and Hamilton's equations, mathematicians began to write down Hamilton's Variation Principle at the head of mechanics, and deduced all other results from it. Similarly, instead of building up electrodynamics inductively with the help of Coulomb's, Gauss's, Ohm's, Joule's, Ampere's and Faraday's laws, it was realized that the theory could be more effectively and logically constructed by assuming simply Poynting's law together with the principle of conservation of energy.

These attempts at the unification of various theories and various branches of knowledge demand the creation of very powerful tools of mathematical analysis. Such tools have been created and developed since the beginning of the present century, and it is of these that I would like to speak in this address.

2. The integral equation.

Gauss* was the first mathematician to be led to an integral equation through a boundary-value problem in potential theory. Later in 1823, Abel [1] was led to the equation:

$$\text{I.} \qquad f(s) = \int^{s} \frac{\phi(t)}{\sqrt{s-t}}\, dt, \quad f(0) = 0,$$

by a consideration of the following problem in Mechanics:

'To determine a curve in a vertical plane such that a heavy particle starting from rest and restricted to move on the curve, shall arrive at the lowest point O in a time which shall be a given function $f(s)$ of the initial height s above the point O.' With the help of Fourier's theorem, Abel showed that the solution of the integral equation (I) is given by

$$\phi(s) = \frac{1}{\pi}\int_0^s \frac{f'(t)\, dt}{\sqrt{s-t}}.$$

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* D. Hilbert: Grundzüge einer. allg. Theorie der Integralgleichungen, Leipzig, p.1, 1912.

Independently of Abel, Liouville [2] was led to the integral equation (I) while studying an extensive class of geometrical and physical questions. One of his problems was as follows: 'An indefinite straight line Y has a uniform distribution of mass symmetrical with respect to the x-axis. It is attracted by the point A situated on this axis at a distance x. The attraction on each point of Y depends on its distance from A, but the law of attraction is not known. The total attraction $\psi(x)$ being given, determine the attraction $F(r)$ of the point A on the point M at a distance r from A'.

The considerations of Abel and Liouville gave rise to a vast number of inversion formulae for definite integrals. The integral equation which we now call of the second kind came up gradually in the course of the 19th century. Its first occurrence can be traced to Liouville (1837). A. Beer [3] found it again in 1856 in connection with a boundary-value problem of the potential theory. These were, however, integral equations with special kernels. It was Paul du Bois-Raymond [4] who, in 1887, first drew attention to the general equation:

$$\text{II.} \qquad \phi(s)+\int_a^b K(s, t)\phi(t)\, dt = f(s).$$

Incidentally, it was du Bois-Raymond who suggested the name 'Integral Equation' which was later adopted by David Hilbert. Before this the problem was called 'Inversion of a definite integral'.

Two methods of iterations or successive approximations were developed to solve the equation (II). Thus

$$\text{III.} \quad \phi_0(s) = f(s), \quad \phi_n(s) = f(s) - \int_a^b K(s, t)\phi_{n-1}(t)\, dt, \qquad (n = 1, 2, \ldots.)$$

and

$$\text{IV.} \quad \begin{cases} f_1(s) = -\displaystyle\int_a^b K(s, t) f(t)\, dt, \\ f_n(s) = -\displaystyle\int_a^b K(s, t) f_{n-1}(t)\, dt, \quad (n = 2, \ldots.) \\ \phi(s) = f(s)+f_1(s)+f_2(s)+\ldots. \end{cases}$$

Liouville [5] was the first to use this method of solution for a particular equation of the second kind. The special nature of his kernel allowed him to prove the uniform convergence of $\phi(s) = f(s)+f_1(s)+f_2(s)+ \ldots$ by explicit calculation. A. Beer [6] applied the method (III) formally to his integral equation. His main contribution lay in the fact that he transformed an integral equation of the first kind which cannot be solved by the

method of iterations to an equation of the second kind which can thus be solved. The convergence of Beer's process was first established by C. Neumann [7], and the method of iterations is usually associated with his name.

Another class of integral equations, the so-called Volterra's equations, were first discovered by J. Le Roux [8] and Vito Volterra [9]:

$$\text{V.} \qquad \phi(s)+\int_0^s K(s,t)\phi(t)\,dt=f(s).$$

Volterra remarked that the treatment of equation (V) was analogous to that of a system of linear algebraic equations in which the rth equation contains the first r unknowns only.

At this stage came the epoch-making discovery of Ivor Fredholm [10]. Inspired by the work of H. Poincaré [11] in connection with Dirichlet's Problem, Fredholm introduced the general integral equation

$$\text{VI.} \qquad \phi(s)-\lambda\int_a^b K(s,t)\phi(t)\,dt=f(s).$$

He conceived the idea of treating this equation on the model of a system of linear algebraic equations which are solved with the help of determinants. Fredholm found the solution of (VI) as a quotient of two integral transcendental functions of λ. He followed faithfully not only the results but also the methods of the theory of determinants. Confining himself to these elementary operations and avoiding the function-theoretical considerations employed by Poincaré, Fredholm was yet successful in formulating a simple theory of quite a general character.

In complete analogy with the theorems for a system of linear algebraic equations, Fredholm proved the following two theorems:

Theorem 1. If $D(\lambda)\equiv\sum\limits_{n=0}^{\infty}(-1)^n A_n\lambda^n=0$, where

$$A_n=\frac{1}{n!}\int_a^b\cdots\int_a^b\begin{vmatrix}K(r_1,r_1),\ldots,K(r_1,r_n)\\ \cdots\cdots\cdots\\ K(r_n,r_1),\ldots,K(r_n,r_n)\end{vmatrix}dr_1\ldots dr_n,$$

then the non-homogeneous equation (VI) has for any arbitrary and continuous function $f(s)$, one and only one solution $\phi(s)$, and particularly the solution $\phi=0$ for $f=0$. In this case the transposed equation

$$\psi(s)-\lambda\int_a^b K(t, s)\psi(t)\, dt = g(s)$$

has also a unique solution.

Theorem 2. If λ is a real root of $D(\lambda) = 0$ of multiplicity p, then the homogeneous equation

$$\text{VII.} \qquad \phi(s)-\lambda\int_a^b K(s, t)\phi(t)\, dt = 0$$

has p linearly independent solutions $\phi_1(s)$, $\phi_2(s)$, $\ldots$, $\phi_p(s)$. Every solution of (VII) is then of the form

$$\phi(s) = c_1\phi_1(s)+c_2\phi_2(s)+\cdots+c_p\phi_p(s),$$

where the c's are constants.

The associated equation

$$\psi(s)-\lambda\int_a^b K(t, s)\psi(t)\, dt = 0$$

has also p linearly independent solutions $\psi_1(s)$, $\ldots$, $\psi_p(s)$. Every solution of this associated equation can be written as

$$\psi(s) = c_1\psi_1(s)+\cdots+c_p\psi_p(s).$$

The non-homogeneous equation (VI) for $D(\lambda) = 0$ is then and only then soluble when

$$\int_a^b f(s)\psi_r(s)\, ds = 0, \quad (r = 1, 2, \ldots, p).$$

3. Hilbert's general theory of linear integral equations.

Immediately after the publication of Fredholm's first paper, the investigations were taken over by David Hilbert[11], who, during the decade (1901–1910), developed a fairly complete theory not only of the solution of linear integral equations, but also of eigenvalues, of the Fourier expansion of arbitrary functions in series of eigenfunctions and of application to mathematical and physical problems.

Hilbert started with the algebraic problem of the orthogonal transformation of a quadratic form in a sum of squares, and then arrived at the solution of the transcendental problem (for integral equations) by a rigorous application of the limiting process when $n \to \infty$. Hilbert established not only the existence of eigenfunctions in the most general case, but gave also the necessary and sufficient conditions for an infinite number of eigenfunctions. His investigations showed that it is not at all necessary to employ ordinary or partial differential equations in the theory of expansion of arbitrary functions. It is actually the

integral equations which form the necessary basis and the natural starting point for such expansions in series.

Hilbert's eigenvalue theory is developed on the same lines as the principal-axes theory of algebra, and if the functions are taken to be integrable L^2, the new theory becomes completely analogous to the algebraic theory.

Hilbert then considered the ordinary differential equation of the Stum-Liouville type

$$\frac{d}{dx}\left\{p(x)\frac{du}{dx}\right\}+\{q(x)+\lambda k(x)\}u=0,$$

for various boundary values, reduced it to an integral equation with the help of the so-called Green's function, and proved the existence of eigenvalues and the expansibility of the given functions in series of eigenfunctions of the problem. He proved a similar result for the self-adjoint partial differential equation:

$$\frac{\partial}{\partial x}\left\{p(x,y)\frac{\partial u}{\partial x}\right\}+\frac{\partial}{\partial y}\left\{p(x,y)\frac{\partial u}{\partial y}\right\}+\{q(x,y)+\lambda k(x,y)\}u=0.$$

A simpler and elegant method for obtaining Hilbert's results directly without using the limiting process was given later by Hilbert's pupil, Erhard Schmidt [12]. Two other of Hilbert's pupils, viz.: Hermann Weyl [13] and R. Courant [14] considered the maximum-minimum properties of the eigenvalues.

4. Applications of linear integral equations.

Integral equations have now become indispensable in many theories in geometry, analysis and the whole domain of mathematical physics. The theory of ordinary and partial differential equations, specially of the equations of mathematical physics, cannot be conceived without the theory of integral equations. The equations of heat, sound and of the potential theory, the oscillations of a linear system, the problems of heat-conduction and oscillation in two and three dimensions, thermoelastic phenomena of straight rods, and numerous other important subjects can be dealt with in a satisfactory manner only through the mediation of integral equations.

In many cases the same result can no doubt be obtained by solving a boundary-value problem for a differential equation, but the employment of integral equations has many advantages: (1) First of all in the differential equation there is an unnecessary splitting-up of the problem into the fundamental equation and the secondary conditions. The integral equation contains in itself all parts of the question. (2) Then it is not necessary to investigate individually problems of different higher orders with a different number of boundary conditions each time. The study of only one kind of integral equations is sufficient. (3) Again,

problems with a single independent variable and those with several independent variables give rise to the fundamentally different theories of ordinary and partial differential equations, whereas in the theory of integral equations there is no fundamental difference between the two cases. (4) Finally, it is seen that problems with several dependent variables which give rise to a system of simultaneous differential equations can be treated with the help of a single integral equation alone.

In problems of mathematical physics, the integral equation is usually obtained through the medium of an ordinary or a partial differential equation or of a system of such equations. In 1910, however, Hilbert [15] made a direct application of the theory of integral equations without bringing in the differential equations at all. He showed that it is a linear integral equation of the second kind with a symmetric kernel which forms the real mathematical basis of the kinetic theory of gases. A systematic formulation of the theory of gases would be impossible without the modern methods of integral equations. For want of an application of integral equations the theory of gases put forward earlier by H. A. Lorentz [16] was deficient, because Lorentz could not prove the existence and uniqueness of the solution of his fundamental equation.

Hilbert also proved that the theory of radiation, and particularly the well-known theorem of Kirchhoff about the relation between the emission and absorption of radiation, could be treated most simply and completely with the help of the theory of integral equations. It would be remembered that all proofs of Kirchhoff's theorem put forward before this were not quite satisfactory.

5. Integro-differential equations.

In classical mechanics and physics the fundamental problem is to explain the phenomena (i.e. to follow their evolution) and to predict them. If the system is known at a given instant, all future states are completely determined. Such an evolution which is known at each instant, and which therefore depends on external circumstances is called 'deterministic'. Thus, in the organic domain, the theories of Lamarck and of Darwin represent the type of deterministic evolution. In the inorganic domain, we have of course the Newtonian mechanics as an instance.

But evolution may depend on internal causes. If at each instant it depends on the actual conditions, it will be a non-hereditary evolution. Only one analytical apparatus, viz., the theory of differential equations, is necessary for the treatment of these non-hereditary phenomena, whether in the organic or in the inorganic domain. All these phenomena obey the principle that the present state determines the future. This principle is a consequence of the conception that each action manifests itself

only at the instant when it takes place, and leaves no heritage. This is the same thing as the assumption that the system does not conserve the memory of those actions which have affected it in the past.

Now, all the phenomena of nature are not really produced in this way. Heredity and memory do exist, but we neglect them to simplify the study of such phenomena. The classical hypotheses are only an approximation to reality. There are a number of phenomena which cannot be explained by the classical theories at all. The analysis proper to such phenomena is that of integro-differential equations.

We shall mention here a few instances where heredity plays a big rôle, and whose explanation requires the integro-differential equations.

(1) It is a fact well-known to engineers that the deformation of an old bridge is not the same at the present moment as it was at the time of its erection.

(2) Similarly, suppose that one end of an elastic horizontal bar is fixed, while different weights can be hung at the other end. First we go on increasing the weights and then take them off gradually. It is observed that the deformation of the rod for any given weight is not the same when the weights are being increased as it is when the weights are being diminished. Thus we see that the actual deformation does not depend only on the actual weight, but also on all the preceding weights.

(3) The phenomena of hysteresis in magnetism are evidently of a hereditary character; they are very important in electrotechnology.

(4) Webster [17] has considered the very interesting question about the best material for making tuning forks. He has been led to apply the conceptions of heredity and integro-differential equations to this problem, and to many others in acoustics.

6. Non-linear integral and integro-differential equations.

When Fredholm and Hilbert built up the theory of linear integral equations in close analogy with a system of linear algebraic equations, it was natural to enquire whether the theorems on a system of non-linear algebraic equations could not be carried over to non-linear integral equations. These considerations have, however, been carried out for the solution 'im-kleinen', that is, in the restricted domain, or, as they are sometimes called, for 'local solutions'.

Let

$$F_r(x_1, x_2, \ldots, x_n, y) = 0 \qquad (r = 1, 2, \ldots, n)$$

be a system of non-linear algebraic equations in n unknowns, where y is a parameter. Suppose, $x_r = a_r$, $(r = 1, 2, \ldots, n)$

is a known solution of this system for the parametric value $y = b$. We know from algebra that for those values of y sufficiently near to b, we can determine solutions of the system with the help of the solution $x_r = a_r$. The two main results in this connection are as follows:

(1) If the Jacobian determinant $\left|\frac{\partial F_r}{\partial x_q}\right|$ does not vanish for $x_p = a_p$ and $y = b$, then one and only one solution of the system exists.

(2) If the Jacobian vanishes, then we get Puiseux's theorems on the branching-off of the solutions for varying parameter.

The existence theorem 'im-kleinen' for non-linear integral equations of the type

$$\phi(s)+\int_a^b K(s,t)\phi(t)\,dt+\int_a^b H(s,t)\{\phi(t)\}^2 dt+\ldots\ldots = g(s)$$

was established by Fubini[18], Volterra[19] and others by the method of successive approximations. Non-linear integral equations of Volterra's type have also been solved by this method for small values of a parameter λ entering into the equation.

E. Schmidt[20] developed in 1908 a theory for non-linear integral equations corresponding to Puiseux's theorem for algebraic equations. Schmidt considered the equation.

$$\text{I.}\quad u(s)+\int_a^b K(s,t)u(t)\,dt = v(s)+F\{u(s),\, v(s)\},$$

where F denotes a non-linear functional operation called an 'integral power series' by Schmidt. The functional $F\{u(s), v(s)\}$ consists of an infinite number of terms of the form

$$u(s)^{\alpha_0}v(s)^{\beta_0}\int_a^b\ldots\int_a^b K(s, t_1, t_2, \ldots, t_n)u(t_1)^{\alpha_1}v(t_1)^{\beta_1}$$
$$\ldots u(t_n)^{\alpha_n}v(t_n)^{\beta_n}dt_1\ldots dt_n,$$

$$(\alpha_0+\beta_0 > 0,\ \alpha_1+\beta_1 \geqslant 1, \ldots, \alpha_n+\beta_n \geqslant 1,\quad n > 0),$$

where $K(s, t_1, \ldots . t_n)$ is a continuous function of all its arguments in (a, b), and where all α, β and n are non-negative integers. The problem is to solve the integral equation (I) for every given continuous function $v(s)$ whose maximum modulus is sufficiently small.

Schmidt proved that there are various possibilities for the solution of (I) according to the solubility or otherwise of the linear homogeneous equation:

II. $$u(s)+\int_a^b K(s,t)u(t)\,dt = 0.$$

(1) Suppose that (II) has no non-trivial solution. Then there exist two positive numbers h', k' such that for every continuous function $v(s)$ with $Max\,|v(s)|<k'$ there exists one and only one solution $u(s)$ of (I) such that $Max\,|u(s)|<h'$. This solution can be expressed as an integral power series in $v(s)$.

(2) Suppose that (II) has only one solution. Then we can find an integral transcendental equation

III. $$L_2x^2+L_3x^3+\cdots = F_1\{v(s)\}$$

in an unknown x with constant L_2, L_3, . . . , which can be found from successive integrations of known functions, and where F_1 is an integral power series in $v(s)$ which vanishes for $v = 0$.

Now, if L_n is the first non-vanishing coefficient of (III), then for each $v(s)$ with sufficiently small maximum, there exist exactly n solutions of (I), that is to say, there is a n-ple branching-off as in the case of algebraic equations.

However, if all L_n vanish, then for $v(s) = 0$, the equation (I) has a non-denumerably infinite number of solutions.

(3) In the third case, suppose that (II) has n linearly independent solutions. Then we get n branching-off equations of the type (III) in n parameters. Every system of sufficiently small solutions of these equations gives us a solution of (I).

A number of non-linear integral equations were also solved by Volterra [21] with the help of his theory of permutable functions and compositions and of his functional calculus. In fact, with the help of this calculus, he was able to show that every problem of analysis which has meromorphic functions for its solution leads to two problems which are correlated to it: (*a*) an integral or integro-differential problem of Volterra's type having integral functions for its solution; (*b*) a problem of Fredholm's type having meromorphic functions for its solution.

In connection with various problems in higher partial differential equations and in hydrodynamics and celestial mechanics, L. Lichtenstein [22] set up and solved a number of non-linear integral equations and integro-differential equations. For instance, he considered the equation

IV. $$\lambda\phi(s) = \sum_{n=1}^{\infty}\int_0^{\pi}\cdots\int_0^{\pi} K_n(s, s_1, \cdots, s_n) \times \phi(s_1)\cdots\phi(s_n)\,ds_1\cdots ds_n,$$

and proved that at least for one value (zero included) of the parameter λ, the equation (IV) has a non-trivial solution. The proof is given by reducing to an existence problem in the calculus

of variations; from all functions continuous in $0 \leqslant s \leqslant \pi$ and satisfying

$$\int_0^\pi \phi^2(s)\, ds = \frac{\pi}{2},$$

it is required to determine those functions which give the highest value to the functional

$$U\{\phi\} = \sum_{n=2}^{\infty} \frac{1}{n} \int_0^\pi \cdots \int_0^\pi K_n(s_1, \cdots, s_n)\phi(s_1)\cdots\phi(s_n)\, ds_1 \cdots ds_n.$$

Lichtenstein proved similarly the existence of an eigenvalue and of a solution of the non-linear integral equation

$$\lambda\phi(t) = \sum_{n=1}^{\infty} \int_0^\pi g_n(s) K(s, t) \left\{ \int_0^\pi K(s, r)\phi(r)\, dr \right\}^{n-1} ds.$$

Solutions of some non-linear integral equations 'Im-grossen' i.e. non-local solutions, have also been given by J. Leray[23], J. Schauder[24] and L. Pomey[25].

The present speaker[26] has considered infinite systems of non-linear integral equations of the type

$$\text{V.} \quad u_n(s) = f_n(s) + \int_0^s g_n(s, t) F_n\{t, u_1(t), u_2(t), \cdots \infty\}\, dt,$$
$$(n = 1, 2, \cdots \infty),$$

and has developed methods for establishing the existence and uniqueness of the solution both in the restricted as well as unrestricted domains. The solution is determined by means of the successive approximations for each $n > 1$:

$$u_n^{(O)}(s) = f_n(s) \quad \text{and for } r \geqslant 1$$

$$u_n^{(r)}(s) = f_n(s) + \int_0^s g_n(s, t) F_n\{t, u_1^{(r-1)}(t), u_2^{(r-1)}(t), \cdots\}\, dt.$$

It is proved first that the series $\sum_{n=1}^{\infty} \left| u_n^{(r)}(s) \right|$

converges uniformly for all s and all r, and further that the double series

$$\sum_{r=0}^{\infty} \sum_{n=1}^{\infty} \left| u_n^{(r+1)}(s) - u_n^{(r)}(s) \right|$$

converges uniformly. Thus it is shown that these approximations converge to a unique limit $u_n(s)$ which is continuous and which satisfies the non-linear integral equation (V) for all n. With the help of this infinite system, the present speaker [27] has been able to solve various boundary-value problems for non-linear partial differential equations of the parabolic and hyperbolic types. Some cases of non-linear integral equations and integro-differential equations have also been investigated by Minakshi Sundaram [28], while working with the present speaker.

Levi-Civita's problem of the propagation of two dimensional surface waves of finite amplitude, Carleman's problem of the theory of heat radiation, specially the problem of thermal equilibrium in the presence of radiation, the problems of heat conduction in deep seas and in crystals are solved by reducing them to non-linear integral equations.

On the other hand, the regular two-dimensional variation problems, the inversion problem in the theory of functionals, the equilibrium figures of rotating fluids, the dynamics of incoherent gravitating media, the hydrodynamics of homogeneous frictionless fluids and a host of other problems [29] can only be treated with the help of non-linear integro-differential equations.

7. Functions of infinitely many variables.

The idea of passing from the finite to the infinite has always been extremely attractive and fruitful in mathematics. Its fundamental significance lies in the fact that through it we are led from algebra to analysis. Thus, to give but one instance, integration is nothing but the taking over of the conception of a sum from the domain of the finite to that of the infinite.

Many attempts to realize this conception and to apply it were made long before the present century. Daniel Bernoilli [30] treated in 1732-33 the oscillating string as the limiting case of a system of n oscillating particles. The principle of passing from the finite to the infinite was applied by Cauchy [31] for demonstrating the existence of integrals of differential equations. But no one understood its deep significance better than Riemann,[32] as can be judged from his remarks on the integration of partial differential equations of hyperbolic type.

For the further development of functional analysis, the introduction in 1886 of this principle into the theory of infinite determinants was of considerable significance. Up to this time some attempts were made to treat infinite systems of linear algebraic equations, but these attempts were not successful. Only when G. W. Hill [33], H. Poincaré [34] and H. von Koch [35] took over the question of infinite determinants and applied the principle of passing from the finite to the infinite, was it possible to build up a theory of solution of infinite systems of algebraic

equations whose theorems were completely analogous to those of n equations in n unknowns.

Thus originated the idea of the function of an infinite number of variables. It is to Hilbert again that we owe the systematic development of the theory of such functions. As we have already pointed out in § 3, Hilbert solved the integral equation by reducing it to a system of n algebraic equations and then making a passage to the limit $n \to \infty$. In this connection he introduced the function $F(x_1, x_2, x_3, \ldots)$ of an infinite number of variables, and developed an extensive theory of linear, bilinear and quadratic forms side by side with the theory of linear integral equations [36].

Hilbert did not confine himself only to the development of a theory of infinitely many variables, but he showed at the same time how the whole theory of solution and the theory of eigenvalues of integral equations can be deduced from it directly.

The connecting link between the integral equations and the equations in an infinite number of unknowns is an infinite system of functions $\{\phi_n(s)\}$ which are defined and continuous in the interval $a \leqslant s \leqslant b$, and which satisfy the following conditions:—

(1) the system is ortho-normal, i.e. for any m, n

$$\text{I.} \quad \int_a^b \phi_m(s)\phi_n(s)\,ds = \delta_{mn} = \begin{cases} 0 \text{ if } m \neq n, \\ 1 \text{ if } m = n; \end{cases}$$

(2) the system is complete, that is to say, for any pair of continuous functions $u(s)$, $v(s)$ the identity

$$\text{II.} \quad \int_a^b u(s)v(s)\,ds = \sum_{r=1}^{\infty} \left\{ \int_a^b u(s)\phi_r(s)ds \,.\, \int_a^b v(s)\phi_r(s)\,ds \right\}$$

is satisfied.

Now consider the integral equation

$$\text{III.} \qquad \phi(s) + \int_a^b K(s, t)\phi(t)\,dt = f(s).$$

Writing

$$x_n = \int_a^b \phi(s)\phi_n(s)\,ds, \qquad f_n = \int_a^b f(s)\phi_n(s)\,ds,$$

$$K_n(s) = \int_a^b K(s, t)\phi_n(t)\,dt,$$

$$\int_a^b \int_a^b K(s, t)\phi_m(s)\phi_n(t)\,ds\,dt = \int_a^b K_n(s)\phi_m(s)\,ds = K_{mn},$$

we get, on account of the completeness relation (II),

$$\text{IV.} \quad \sum_{n=1}^{\infty} \{K_n(s)\}^2 = \int_a^b \{K(s, t)\}^2 \, dt;$$

$$\sum_{n=1}^{\infty} f_n^2 = \int_a^b \{f(s)\}^2 \, ds,$$

$$\sum_{m=1}^{\infty} \sum_{n=1}^{\infty} K_{mn}^2 < \int_a^b \int_a^b \{K(s, t)\}^2 \, ds \, dt.$$

Thus the equation (III) can be written as

$$\text{V.} \qquad \phi(s) + \sum_{n=1}^{\infty} K_n(s) x_n = f(s).$$

Further, for a continuous solution $\phi(s)$ of (III), the sum of squares

$$\text{VI.} \qquad \sum_{n=1}^{\infty} x_n^2 = \int_a^b \{\phi(s)\}^2$$

is seen to be convergent. Again, on account of Schwarz's inequality $\{\Sigma u_n v_n\}^2 \leqslant \Sigma u_n^2 \Sigma v_n^2$, it follows from (IV) that the series $\underset{n}{\Sigma} K_n(s) x_n$ is uniformly convergent in (a, b). Hence

$$\int_a^b \phi(s)\phi_m(s) \, ds + \sum_{n=1}^{\infty} x_n \int_a^b K_n(s)\phi_m(s) \, ds = \int_a^b f(s)\phi_m(s) \, ds$$

or

$$\text{VII.} \quad x_m + \sum_{n=1}^{\infty} K_{mn} x_n = f_m \qquad (m = 1, 2, \ldots).$$

Thus we have the theorem that the Fourier coefficients x_n of every solution of the integral equation (III) give a solution of the system (VII) with convergent sum of squares.

If $f(s) \equiv 0$, that is to say, if the integral equation is homogeneous, then $f_n = 0$ for all n, so that x_n satisfy the system of homogeneous equations

$$\text{VIII.} \quad x_m + \sum_{n=1}^{\infty} K_{mn} x_n = 0 \quad (m = 1, 2, \ldots .).$$

Conversely, if $x_1, x_2, \ldots$ is a system of solutions of (VII) such that Σx_n^2 is convergent, then it follows that the series

$\Sigma_n K_n(s)x_n$ is uniformly convergent, and therefore the function $\phi(s) = f(s) - \Sigma_n K_n(s)x_n$ is continuous. Then

$$\int_a^b \phi(s)\phi_m(s)\,ds = \int_a^b f(s)\phi_m(s)\,ds - \sum_{n=1}^{\infty} x_n \int_a^b K_n(s)\phi_m(s)\,ds$$

$$= f_m - \sum_{n=1}^{\infty} K_{mn}x_n = x_m \quad \text{from (VII).}$$

This shows that x_m is the Fourier coefficient of $\phi(s)$, so that from (II) we obtain

$$\sum_{n=1}^{\infty} K_n(s)x_n = \int_a^b K(s,\, t)\phi(t)\,dt.$$

Thus we see that $\phi(s) = f(s) - \Sigma_n K_n(s)x_n$ is a solution of the integral equation (III).

Further, it is evident from (VI) that the Fourier coefficients of a continuous function all vanish only when the function itself identically vanishes. Thus, from a system of solutions of the homogeneous algebraic equations (VIII), we get solutions of the homogeneous integral equation. Also, a number of systems of solutions of the homogeneous algebraic equations is linearly independent only when corresponding solutions of the homogeneous integral equation are linearly independent. Finally we see that the transposed integral equation

$$\psi(s) + \int_a^b K(t,\, s)\psi(t)\,dt = g(s)$$

corresponds to the system of algebraic equations

$$x_m + \sum_{n=1}^{\infty} k_{nm}x_n = g_m \qquad (m = 1, 2, \cdots).$$

Thus the complete equivalence of the solution theory of linear integral equation (III) and that of the system of linear algebraic equations (VII) is established.

In 1914 Lichtenstein[37] made his well-known application of Hilbert's theory of infinite bilinear and quadratic forms. He developed a method of dealing with the boundary-value problems by reducing them directly to equations in an infinite number of unknowns without reducing them first to integral equations. In subsequent years this became a very powerful method for the treatment of such questions for ordinary and partial differential equations.

Hilbert and his pupils Hellinger [38], Toeplitz [39] and others considered in detail the 'Vollstetig' and bounded bilinear and quadratic form in an infinite number of variables, and developed in this connection a theory of infinite matrices and of principal-axes transformations. It was this last theory which supplied the mathematical foundations of modern, quantum mechanics [40]. An elaborate geometry of the Hilbertian space has also been developed [41]. Among its many applications we may mention the generalized absolute differential calculus which includes Ricci's calculus as a particular case.

8. The theory of functionals.

We have seen that both from the side of mathematics and from that of natural philosophy we are compelled to introduce the idea of functions of infinite number of variables. If we consider a natural phenomenon as the effect of a finite number of causes, we are making only an abstraction because we are neglecting elements which are supposed to be very small compared to others which are taken to be preponderant. In this way we make only an approximative study of the phenomenon for a full and complete examination of which it would be necessary to pass from a finite to an infinite number of variables. Thus, to take a general example, if a phenomenon depends on a physical field, and if the field, regarded as a continuum, is varied, then the changes of the phenomenon would depend on an infinite number of variables. Similarly, we have already remarked that in phenomena where heredity and memory of the past play a big rôle, it is essential to employ functions of infinitely many variables.

Let us consider an old problem of isoperimetry, viz. that of finding a plane curve of given length which encloses the greatest possible area. The area here is evidently a function of the enclosing curve, and since the curve can be represented as an ordinary function, the area can be considered as a quantity which depends on all the values of a function. It is therefore a function of an infinite number of variables. A more general example is provided by the integral

$$I = \int_a^b f\left(x, y, \frac{dy}{dx}\right) dx$$

which depends on all the values of the function y in the interval (a, b).

Thus the definite integral and the calculus of variations present the first two instances of the idea of a functional. But the credit of recognizing the individuality and the importance of this new conception in mathematics goes to Pincherle [42], and above all to Volterra [43]. The functional calculus was created

in 1887 when Volterra published his researches under the title 'functions depending on other function'. He changed the name later to 'functions of lines', but the term 'functional' which is now generally accepted was proposed by Hadamard. Thanks to the profound researches of Volterra, Hadamard and a brilliant congregation of other workers, the functional analysis has developed extensively, and has penetrated deeply into the various branches of pure and applied mathematics. Everything concerning integral, integro-differential, and functional equations, investigations on functional spaces, the calculus of variations in its broadest sense, questions involving effects of the hereditary type—all these different subjects have now been unified in one general theory of functionals. These different theories, viz. those of integral equations, calculus of variations, etc., then become only so many chapters in the theory of functionals. Moreover, the theory of functionals can be applied to mechanics, mathematical physics, biology, statistics and sociology.

Investigations on the theory of functionals can be divided into two main groups which are called 'functional algebra' and 'functional analysis'. The first consists of problems where the unknowns are ordinary functions, but which become a part of the functional calculus on account of the methods which are employed to solve them. To this category belong the theories of integral and of integro-differential equations. The second group, viz. that of functional analysis, consists of those problems in which the unknowns are functionals, or more generally of those problems which cannot be conceived independently of the notion of a functional.

It seems desirable to give a brief résumé of the precise meaning of the functional, and also of the fundamental notions of the calculus.

For the sake of definiteness, we consider the function $x(t)$ of a single variable t taken in the interval (a, b). The functional depending on the argument-function $x(t)$ is represented by the notation $U[x(t)]$ or simply by $U[x]$. In general the functional depending on the three argument-functions $x(t)$, $y(t)$, $z(t)$, and on two parameters λ, μ will be represented by $U[x, y, z\,;\ \lambda, \mu]$. As we have remarked the functional analysis appears as a natural generalization of the theory of ordinary functions, and can be deduced from the former by the method of proceeding to the limit. Thus, if we divide (a, b) into n equal parts, and if we represent the function $x(t)$ asymptotically by a function $X_n(t)$ which is constant in each of these intervals such that the constant value of $X_n(t)$ in the interval $\left(\frac{i-1}{n}, \frac{i}{n}\right)$ is denoted by x_i, then the functional $U[x]$ would be reduced for $X_n(t)$ to a function $u_n(x_1, x_2, \cdots, x_n)$ of n variables. Hence the

functional in such cases can be defined as the limit of the function $u_n(x_1, x_2, \cdots, x_n)$ when $n \to \infty$. Even if this procedure does not always provide a rigorous demonstration, it constitutes a remarkable method of induction for obtaining fundamental results of the functional analysis. Volterra calls this method 'the method of passing from discontinuous to continuous'.

Generalizing the idea of representing a function of n variables by a point in an ideal space of n dimensions, each function $x(t)$ is represented by a point $[x]$ in a space of infinite dimensions, which is called 'functional space'. A functional of $x(t)$ will then become a function of the point $[x]$. The notions of the bound, limit and continuity of a function can then be generalized to give analogous notions for a functional. There would be, of course, several definitions possible according to the definition which we adopt for the distance between two points $[x]$ and $[y]$ of functional space, representing the two functions $x(t)$ and $y(t)$. This distance is commonly defined as the number r, positive or zero, given by

$$\text{I.} \qquad r^2 = \int_a^b \{y(t) - x(t)\}^2 \, dt.$$

The functional field in this case will consist of those functions whose square is summable. Other definitions of distance will give rise to other functional fields.

Fischer [44] and Riesz [45] have studied the geometry of this functional space, and have shown that it is remarkably similar to the geometry of n-dimensional space. Thus, consider an infinite system $\{x_n(t)\}$ of ortho-normal functions, and an infinite sequence $\{c_n\}$ of coefficients such that the sum $\sum_{n=1}^{\infty} c_n^2$ is finite. Fischer and Riesz have shown that the series

$$\text{II.} \qquad c_1x_1(t) + c_2x_2(t) + \cdots + c_nx_n(t) + \cdots$$

converges in the mean to a function $x(t)$ such that

$$\text{III.} \qquad \int_a^b x^2(t)\, dt = c_1^2 + c_2^2 + \cdots + c_n^2 + \cdots$$

Conversely, if a function $x(t)$ can be represented by a series of the type (II) which converges in the mean, then the coefficients c_n are given by the formula

$$\text{IV.} \qquad c_n = \int_a^b x(t)x_n(t)\, dt.$$

The $x_n(t)$ can therefore be considered as unit vectors in a rectangular co-ordinate system in functional space. Then $x(t)$ would

be the vector from the origin $x(t) \equiv 0$ to the point $[x]$ representing $x(t)$, whose length l would be given by $\left\{ \int_a^b x^2(t)\,dt \right\}^{\frac{1}{2}}$. The Fourier coefficient c_n would be the component (length of projection) of $x(t)$ in the direction of the unit vector $x_n(t)$. The relation (III) would then be only the expression of the Pythagorian Theorem

$$l^2 = \sum_{n=1}^{\infty} c_n{}^2.$$

9. DIFFERENT BRANCHES OF THE FUNCTIONAL ANALYSIS.

Functional analysis has been studied and developed along various lines corresponding to those of the theory of ordinary functions.

A functional $U[x]$ depends on the argument-function $x(t)$ which can be taken to define a line. If one point of the line is altered, we get what is called a 'derivative' of the functional. Supposing such modifications of a line made at all its points we obtain a 'differential' or 'variation' of the functional. We can then pursue the study of successive differentials, and then arrive at an analytic development analogous to that of Taylor. Then we can try to find the maxima and minima of a functional. This will necessitate an investigation of the conditions under which the differential of a functional would vanish. These investigations are very much difficult and complicated, and much work remains to be done in this respect.

If we consider the various terms in the Taylor expansion of a functional, we are led to analytic forms in an infinite number of variables, thus giving rise to a new algebra closely connected with the ordinary algebra. In the first place each chapter of the ordinary algebra leads to a corresponding problem obtained by Volterra's principle of passing from discontinuous to continuous. At the same time this correlation offers us in the majority of cases practical and easy solutions, because these new problems can be considered as limiting cases of the problems of ordinary algebra. Very often the solutions are only limits of the known algebraic solutions. A well-known instance of this is provided by the general theory of an infinite system of linear equations.

The theories of functions of several variables and of multiple integrals have also been generalized to give corresponding theories in functional analysis. A theory of functional derivative equation has been built up by Hadamard [46] and Levy [47], to correspond to the theory of differential equations. The functional derivative equations consist of relations between the functional derivatives of a functional, the functional itself and the independent variables. These equations can also be obtained

by the usual process of passing from the finite to the infinite, from ordinary total differential equations, and from partial differential equations.

10. Applications of the Theory of Functionals.

The first application of the functional analysis was made to the calculus of variations with the help of Volterra's extension [48] of the Hamilton-Jacobi theory. We know that this theory plays an important rôle in the integration of the equations of mechanics. It has its origin in the fact that the differential equations of mechanics are nothing but the Euler equations of an Extremum problem concerning the action integral. It is well known that many other problems of mathematical physics can be reduced to problems of the calculus of variations. In the development of the science of Physics, there has often been a tendency to reduce natural problems to the question of finding a minimum. This has been due to the conviction that Nature, in its manifestations, tends to accomplish various phenomena at the lowest possible expenses. The problems of mathematical physics thus depend on the extremum of a multiple integral, making it necessary to consider the integral as a functional of the field of integration. It would then be impossible to obtain a generalization of the Hamilton-Jacobi theory without the aid of the functional analysis.

Volterra [49] has insisted on this point from the very beginning of his researches. He has pointed out, for instance, that Hamilton's principle can be developed in two different directions: the so-called principle of stationary action and the principle of variable action. It is the latter that requires the theory of functionals. In it, the action is considered as a function of the final values of the integrals and of the time, so that for a continuous system with an infinite number of degrees of freedom the action becomes a function of an infinite number of variables, and therefore a functional. 'It follows that the extension of the principle of variable action to the cases of electricity, magnetism, elasticity and so on, and in general to the classical questions of mathematical physics, leads to a corresponding series of principles which cannot be enunciated without the terminology of functionals, and which find their development within the sphere of the theory of functionals'.

Shortly after the appearance of Volterra's first researches, Hadamard [50] Tonelli [51] and others applied these conceptions to obtain direct and rigorous methods for treating questions of the calculus of variations. These questions consisted mainly of the following three successive steps:

(1) To obtain the equations which express the vanishing of the first variation. These are the well-known equations of Euler.

(2) To determine the lines or surfaces which verify Euler's equations and which satisfy the boundary conditions of the problem, or at least, to establish the existence of such lines and surfaces.

(3) To investigate whether these lines or surfaces really give a maximum or a minimum.

Now in the classical method of the calculus of variations it was always easy to write down Euler's equation, but the other two questions, and specially the third, presented great, almost insurmountable difficulties. Functional analysis has made the direct investigation of these questions quite easy, and has thus given new life to the calculus of variations.

These investigations have contributed greatly to bring about a unification of the whole structure of mathematical physics. Moreover, the new method gives us a ready criterion for examining whether the various expressions for natural laws are in an invariant form agreeing with modern relativistic conceptions. The employment of a variational form for the expression of a physical law makes the change of variables easier, so that we can conveniently investigate the invariance of our equations for a change of the frame of reference. The direct method is often employed in the modern theories of physics as an instance of which can be mentioned the quantum-electrodynamics proposed by Heisenberg and Pauli [52].

Another field for an application of the functional analysis is provided by the celebrated principle of Dirichlet, and similar existence theorems. This principle postulates the existence of a function continuous along with its derivatives in a domain D with the boundary S, taking given values on S and making the integral

$$I = \iint_D \left\{ \left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial y}\right)^2 \right\} dx\, dy$$

a minimum.

The corresponding Euler equation is Laplace's equation of the potential theory, viz. the equation

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 0.$$

We have thus to find a continuous solution of this equation which takes given values on S. This is called Dirichlet's problem. Similar remarks can be made for the solutions of boundary-value and eigenvalue problems of linear partial differential equations of elliptic type.

Gauss and Riemann believed that the existence of the function $\phi(x, y)$ was assured because the integral I was always

positive. Weierstrass raised an objection to this assumption, and gave simple examples of minimum problems which had no solution. This method of proof was then abandoned and efforts were concentrated on solving Dirichlet's problem, i.e., on finding a solution of the differential equation for the given boundary conditions. Various methods, viz. those of Neumann [53], Schwarz [54], Poincaré [55] and Fredholm [56] were developed to solve the problem, but these had no connection with the calculus of variations.

Then, inspired directly by the theory of functionals Arzela [57] tried to go back to Dirichlet's principle, and attempted to give a rigorous proof of the existence of the minimum under certain conditions. It was Hilbert [58] who, in the year 1900, furnished such a rigorous and complete demonstration of Dirichlet's principle, and obtained a definite result with the help of the theory of functionals. The work has been subsequently continued by Levi, Fubini, Lebesgue, Zaremba and various other writers [59].

The idea of treating the integral and integro-differential equations as chapters in the theory of functionals was already mooted out by Volterra [60] in 1913. Subsequent developments have revealed the close connection between these two subjects. The general methods employed today for treating the integral equations in all their generality are effectively the same as those which have served for making a passage from ordinary functions to functionals. In both cases, the basic concept is a systematic and uniform application of the principle of passing from discontinuous to continuous. The powerful theories of integral and integro-differential equations, with all their applications to geometry, analysis, mechanics and mathematical physics, are thus found to be only branches of the still more powerful theory of functionals.

The method of functionals and particularly of integral equations has been applied by Proudman [61], Matteuzzi [62] and others to the study of the oscillations or tides of lakes. This phenomenon was first observed in the lake of Geneva, where, owing to its elongated form, the changes of level sometimes reach a couple of meters. Extending a method used by Lagrange for the theory of the vibrations of strings, Proudman divides the lake into an infinite number of narrow strips, and studies their vibrations, making use of infinite determinants. Matteuzzi, however, applies the general theory of integral equations, and obtains all the results directly. The same method has been applied by Poincaré [63] and others to the study of the problem of oceanic tides.

In 1914 Volterra [64] suggested that functional analysis should be applied to the study of continuous systems, and especially those consisting of swarms of corpuscles not connected by links that can be expressed by means of differential relations.

G. C. Moisil [65] carried out this suggestion. He attached a set of functions which can be considered as co-ordinates, to each configuration of a continuous and variable system. Choosing a suitable metric for the functional space, and applying the tensor calculus, he arrived at differential equations analogous to Lagrange's equations in classical mechanics. The theory has a practical application in the study of the movement of a flexible and inextensible wire.

Volterra and his co-workers [66] have made an extensive use of functionals in the theories of elasticity and of hereditary phenomena in elasticity, electro-magnetism and mechanics. The theory of functionals has recently been applied to ballistics,[67] political economy,[68] statistics [69] and to a biologico-mathematical theory of the fluctuations of species living together [70].

11. The general analysis of Frechet and Moore.

We have seen that the independent variable of the functional analysis is not numerical, as in the ordinary theory of functions. but a line, a surface or a function. From 1904 onwards Frechet [71] and Moore [72] began generalizing the analysis by discarding the concrete variables and considering those of any nature whatever. They proposed to extend the infinitesimal calculus to the case in which the nature of the variables is not specified. Not only was the numerical variable generalized, but the numerical function was replaced by a function of an arbitrary nature. Thus Frechet and Moore studied the relations between two elements of an abstract type. This subject is called 'general analysis' and has developed a great deal in recent years. This new analysis proceeds by making an abstraction of all those concepts which are common to several known and allied theories. These theories are then generalized by removing from them any particular properties that are related to the concrete elements on which they are based. A familiar example of this passing from the concrete to the abstract is provided by the concept of a vector which is the generalization of the concrete notions of velocity, accelleration, force, momentum, etc.

General analysis is not concerned with special cases of classical mathematics. Thus it does not deal either with functions continuous in an interval as is done by the theory of integral equations, or with the points of a n-dimensional space as is done by the algebraic theory of systems of n-linear equations, or with points in Hilbert space as is done by the theory of functions of an infinite number of variables, but with elements of an abstract aggregate. Its theorems contain those of integral equations as well as of finite and infinite systems of algebraic equations.

General analysis has not only given us several new subjects such as the theory of dimensions and topology, but it has also brought about a unification of various results in the classical theories. Thus the theory of integral equations becomes a particular case of the theory of transformations in abstract spaces and their inversions.

12. The theory of functional operators.

With the introduction of the idea of abstract spaces in analysis, we can easily pass over from the special theory of functionals to the general theory of operators.

The term 'functional operation' signifies any operation carried out not on numbers, but on functions.

Let E_1 and E_2 be two spaces formed of any elements whatever, provided only that the associative law of addition and the zero element are supposed to be defined in them. Let $y = U(x)$ be a function (operation, transformation) which connects an element y of E_2 to every element x of E_1. The functional is only a particular case of the operator U when E_2 is the space of real numbers.

If for any two elements x_1, x_2 of E_1, the relation

$$U(x_1+x_2) = U(x_1)+U(x_2)$$

is satisfied, the operator $U(x)$ is said to be 'additive'. If, further, E_1 and E_2 are metric spaces, i.e. if in each of them the distance between two elements is defined, the operator $U(x)$ is called 'continuous'. An operator which is additive and continuous is called 'linear'. Familiar instances of operations are those of differentiation and definite integration considered by Leibnitz [73] and later by Lagrange [74] and others [75]. Similarly, the ordinary complex numbers can be interpreted geometrically as transformations of a coplanar set of vectors, and are thus linear operators. So also, the quaternions as defined by Hamilton, are operators on three-dimensional vectors. These can be generalized further to n-dimensional operators.

A symbolic form of the operator calculus was developed and used by Heaviside [76] in connection with his researches in electro-dynamics. Giorgi [77] and others applied Heaviside's methods to the solution of numerous problems in mathematical physics, and to the integration of differential equations.

But the principal development of the operator calculus, so far as concerns linear functional operations in the field of analytic functions, is due to the work of Pincherle [78]. It was extended in various directions by Volterra [79], Calo [80], Bourlet [81] and a host of other workers [82].

The theory of operators has now become an essential part of many of the most important domains of mathematics. We have seen that the theory of integral equations and the calculus

of variations are contained as particular cases of the theory of functionals, and therefore of the general theory of operators. In this theory, we see the methods of classical mathematics blending harmoniously with those of modern mathematics. It gives us completely new interpretations of many results in the theory of sets or in topology. Thus, for example, Birkhoff and Kellog have demonstrated that by means of the theory of operators the topological theorem on the invariant point can be translated to give the classical existence theorem for differential equations. The operator theory brings about a certain unity in different branches of mathematics sufficiently remote from each other. For instance, the theorem on the continuation of an additive functional resolves simultaneously the general problem of measure as well as the problems of moments and of existence of the solution of a system of linear equations in an infinite number of unknowns. Thus a really profound insight into many important branches of mathematics such as the theory of functions, integral and integro-differential equations, calculus of variations, theory of sets, topology and theory of dimensions, is possible only with the help of functional operators.

On the other hand, modern theories of physics make much use of the operator theory. Thus, apart from classical mechanics and electro-dynamics, the subject of quantum mechanics in its modern developments is based entirely on the theory of linear operators. This theory plays the same part in quantum mechanics as tensor analysis plays in the theory of relativity. Quite recently the quaternionic operators have been applied to relativistic quantum mechanics [83].

It is well known that many of the laws of quantum mechanics are not in a covariant form. For instance, the uncertainty relation is not invariant for transformations of the Lorentz group. The non-covariance of quantum mechanics is due to the fact that in it, as in the classical theory, time plays a particular rôle, viz. that of the parameter. This is contrary to the relativistic idea that all the co-ordinates of space–time have the same status. For the mathematical description of physical phenomena, the world-point (x, y, z, ict) should be taken as parameter. The quaternions are admirably suited for this purpose. The application of quaternions has the advantage that it conserves the four-dimensional character of physical quantities all along the calculations. The q-numbers and the c-numbers of quantum mechanics thus become quaternions. The dynamical variables are therefore not simply Heisenberg's matrices, but quaternionic matrices.

The fundamental relations of quantum mechanics such as the Ritz combination principle, the quantum conditions, the equations of motion and Heisenberg's uncertainty relations, can then be generalized in a quaternionic form in the same way as

Dirac's relativistic equation is a generalization of Schrödinger's wave equation. Dirac's equation itself can be obtained from the quaternionic mechanics with the help of the most general Lorentz transformation. The relativistic quantum mechanics thus becomes a mechanics of the quaternionic matrices.

The theory of functional operators is playing an increasingly important rôle in the whole domain of mathematics and its applications. We can readily agree with Hadamard when he says that it 'is one of the most powerful tools of research in contemporary mathematics'.

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SECTION OF PHYSICS

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Presidential Address

(*Delivered on Jan. 4, 1941*)

THE RÔLE OF APPLIED PHYSICS IN INDUSTRY.

I would like to present before you all, some particulars of the subjects with which I have been intimately associating myself during the last few years. I have been feeling for some time that time is now ripe to consider the important rôle which the scientists of our country have to take up in associating themselves with the industrial development of our motherland. It would be necessary for us to take into account and to realise that in the last fifty years applied physics has exerted a more powerful beneficial influence on the intellectual, economic and social life of the world than has ever been exerted in a comparable time by any other agency in history. Its main sub-divisions, such as applied heat, applied optics, applied acoustics, applied electricity and magnetism, and applied mechanics, illustrate its scope. Anything we know about these subjects and whatever uses are made of such agencies as light, heat, electricity or the different materials in their different states fall within its field and are the contributions of applied physicists to human welfare.

Average citizen and man of the world have little comprehension regarding applied physics, since all the different people whose life-work really happens to be applied physics do not call themselves by that name. There has been a very interesting trend in applied physics by which great branches of its specialised interests have been appropriated by special groups of applied physicists who call themselves engineers as soon as a systematic method for the application of its principles has been developed in special fields. Thus we have civil engineers, mechanical engineers, electrical engineers, automobile engineers, aeronautical engineers, communication engineers, mining and metallurgical engineers, illumination engineers, motion picture engineers, radio engineers, chemical engineers and diverse others whose activities are wholly or largely concerned with the application of physics to practical ends. Considering 'Civil Engineering',

which is one of the oldest examples of applied physics, one finds that its field is based on the strength of materials, hydraulics and applied optics. Others like the radio engineering and motion picture engineering are based on discoveries within our lifetime. Turning our attention to metallurgical engineering, a very old practice, and the more recent chemical engineering involving important applications of the chemical science, it is easy to notice that the bulk operations are based on those applications which form the elements of mechanical engineering.

Besides these applied physicists, who group themselves as engineers, one finds astronomers, meteorologists, opticians and optometrists and many similar groups, who deal with physical instruments and theories in their special fields of activities. Hence it would not be too much to state that the economic, social and intellectual influence of applied physics is based on the contributions to knowledge, to industry, and to the art of living which have all emanated from the diverse elements which are but manifestations evolved from the knowledge of physics. Furthermore, one is cognisant of the fact that new knowledge and applications are rendered available more rapidly than ever before.

Let us try to explain our position a little more clearly and let us treat it under three different categories. Firstly, those industries which are based more upon ancient art which has been developed largely by practical experiences. In this category one finds such activities as the construction of buildings, highways, bridges, and dams; the production of metals, alloys and textile materials; the use of natural resources, such as power from wind and water, coal and oil. In all these fields there is an art which has been handed down from antiquity and which has been more or less improved by invention and discovery of new materials and methods. In these fields there is noticed a tendency for misunderstanding and conflict of ideas between the so-called practical workers on the one hand and the scientists on the other. The practical men have a great force of tradition behind them and the general public has a feeling of conservatism to oppose the introduction of new materials and new technique supplied by the scientists. The trend towards the scientific attitude is, however, unmistakable and is augmented partly by force of competition and examples, set up by more enterprising members. The second category embraces those industries which have been built upon more recent scientific discoveries. In this, one finds communications, air transportation, motion pictures with sound and colour accompaniments, illumination and the generation and diverse utilisations of electric power. It is noteworthy that since these industries have been created by research, the organisations, which are taking part in their introduction, would tend to become obsolete as soon as the research activities are allowed to diminish in vigour. The

third category includes those groups whose activities rest on the basis of other sciences, such as, chemistry, biology, etc. Here one finds the chemical industries, the industry of drugs and medicine which though not directly derived from physics but to which it is contributing an ever-increasing assistance through tools and measuring instruments, methods and interpretative concepts. In the field of medicine, the X-ray has been marvelously developed for diagnostic examination and for therapeutic treatment of certain glandular disorders and growths, notably cancer. In the most recent developments primarily for investigations of atomic nuclear structure there is a bye-product exciting new suggestions for medical application. X-rays at a million volt or more have been finding applications for treatment of deep-seated cancer. Neutrons produced in nuclear transformations have been found to produce effects different from X-rays or radium and suggest advantageous application in modern therapy. Artificially produced radioactive preparations offer interesting possibilities for treatment and open up avenues for a great variety of new physiological investigations on a number of lines, such as blood circulation, tissue building and disintegration and the function characteristics of various organs of human and animal bodies. In physical therapy the application of high frequency diathermy and bloodless surgery is but one example of the application of forces studied by applied physicists and applied by the medical practitioner. The application of heat agency in the discriminative destruction of germs and growths is one of the newest forms of physical therapy which operates on the different threshold principle based on resistance and temperature. Quite recently an improved technique is being developed which consists in raising the body temperature locally by means of electromagnetically produced high frequency currents within the body in the region to be treated while the rest of the body is kept within safe limit by special cooling. Finally, it is not an idle boast to state that all the measuring instruments beginning from the thermometers to the portable cardiographs and the multitude of other devices are but the gift of applied physicists to the science and practice of medicine.

I shall now place before you some of the specific industries and would indicate how applied physics is instrumental in their development and growth. In this selection I shall take up first 'Building Industry' and 'Metal Industry' as representatives of a class having age-old traditions behind it. I shall next take up 'Electrical Power Industry' which has been effective in revolutionising all the modern industries, then 'Refrigeration Industry' which is the direct outcome of laboratory investigations. From the modern industries I shall choose 'Automobile Industry' and 'Aeronautics Industry', the last being the youngest

of the lot and still in the adult stage requiring constant help from researches in applied physics.

Building Industry.

Here one finds that all our structures built to date, rest on earth and a fairly large part of the world's construction cost is in working the earth; yet through the centuries the very bottoms of our buildings have been designed on an empirical basis. It is only very recently that the investigations regarding soil mechanics have been undertaken. The first International Conference on Soil Mechanics and Foundation Engineering held at Harvard University in the summer of 1937 has disclosed a wealth of outlook and previous lack of understanding of some of the essential aspects of the subject. The problems arising under soil mechanics in connection with design of foundations, the stability of cuttings, though manifestly of the greatest concern to the civil engineers and contractors, have had to be treated empirically in the past owing to the absence of reliable scientific knowledge. For the most part, the formulae used for estimating the behaviour of soils have involved such drastic assumption as seriously to impair their validity for anything like general application, and it has not been difficult to prove by systematic experiments to demonstrate that such relations as Coulomb's Law, for instance, are, to say the least, unsatisfactory. The analytical approaches to soil mechanics suggested by Petterson, Terzaghi, Jurgenson and others appear to be far more promising than any of the old methods. The so-called bearing values of the major soil types embodying an accumulation of practical experience, obviously took no account of numerical factors influential in particular set of conditions and were uncertain to a degree and often demanded uneconomical factors of safety and expensive procedures of foundation design. The modern approach to this class of problem seeks rather to understand the mechanism by which settlement occurs, to take account of variations in the type, depth and thickness of the soils in adjoining localities and underlying strata, and to place the effects of weather and secular changes on a rational basis.

At the present time an essential part of research on the subject is to obtain 'settlement records', as they enable correlation with the theory to be made and the types of settlement to be classified. From the experimental work so far undertaken it has been found that there are three types of settlement depending on the nature of the substratum. In the case of sand, the movements do not continue for any appreciable time after the construction, whereas for clay, the settlement continues for a long time after construction approaching a horizontal asymptote. With plastic clays and materials of high organic content a similar gradual settlement is noted, but here the asymptote

is inclined. The settlement of a building with clay as the most important substratum may be quite small at the end of the construction, yet the final or total settlement may be many times greater. The procedure adopted for settlement analysis consists of the following. Firstly, the cores of the various substrata are obtained with a well-boring kit and for large structures one has to take the cores up to a depth of 50 ft. The second step is to ascertain the consolidation characteristics of the samples so obtained by laboratory tests. The consolidation characteristics were first studied by Terzaghi with the help of the special instrument devised by him and called oedometer. In the instrument the sample of core material of definite thickness is placed in a brass cylinder between two porous stones which are in contact with water. The conditions of saturation and lateral restraint are thus simulated in the laboratory. Now, clay has an open microstructure as has been found from X-ray studies, but the dimensions of pores are very small and the resistance to flow is correspondingly high. Under compression the clay as a whole can suffer volume decrease mainly by the escape of some water from its pores until an equilibrium density is established. Theoretically this would take infinite time but in the laboratory such a stage is attained in about two days. By gradual increase of pressure similar consolidation process takes place and a new equilibrium density is reached. A number of such data gives the relation between the density and effective pressure. This is technically denoted as the void ratio for the material in question. Thirdly, a mathematical analysis of the stresses set up in the substrata by the foundation load is carried out. The theoretical aspect is that of finding an expression for the vertical stress at any point in a semi-infinite elastic solid due to a load on its surface. This has been worked out by Boussinesq as early as 1885. In order to arrive at the rate of consolidation one has to take account of the hydrodynamic excess pressure 'w' in the pore water causing a flow at a distance 'z' from the surface of drainage after a time 't' from that of the application of the load and also the coefficient 'c' of consolidation. The fundamental equation has a general nature as $c\frac{\partial^2 w}{\partial z^2} = \frac{\partial w}{\partial t}$. If the degree of consolidation 'μ' is known from the data of compression at a time 't' and the total compression where μ is the ratio between the two aforesaid quantities, one can solve the differential equation in the form $\mu = f\left(\frac{\pi^2 ct}{4d^2}\right) = f(N)$, where '$d$' is the maximum drainage path. The relation between μ and N has been evaluated for a number of special cases by Terzaghi and Fröhlich with the help of data secured with oedometer. Now, for any value of 't', 'N' is known from the laboratory tests and 'd' from the

boring records; the time settlement curve for any part of building structure can be predetermined. It is, therefore, possible to design a foundation with a measure of certainty not possible with the older empirical methods.

The paramount conclusions of the new work may be concisely stated as follows:—(1) The strains in a foundation which principally determine settlement and soil reaction extend at least to a depth equal to about twice the lesser horizontal dimension of the super-structure. (2) The depth of the foundation below the surface level has an important effect on the distribution of strains in the soil below it. (3) The pile driving formulae are valueless for computing pile capacities in plastic soils owing to the fact that the side friction (which is the main support of the static support in such materials) is temporarily eliminated by water lubrication during driving. (4) The settlement in plastic materials and those containing organic constituents in some proportion is not uniform under uniform loading but tends to be greatest in the middle of the loaded area. (5) Compressibility of the soil materials depends on the initial arrangement, size and shape of the structure and grains as well as on the water content. For fine grained materials compression occurs very slowly and may take many years to complete owing to the water being retained in the pores. Its nature can be understood from micro-structure examinations and suitable laboratory experiments on samples of materials in an undisturbed state. (6) The shearing resistance of granular materials depends on the stresses in the contained water and their ability to escape from the structure. (7) The lateral pressures of granular materials are affected to an enormous degree by small motions of the retaining surface within the mass itself so that arching may entirely modify the pressure and its distribution. (8) The existence of rather deep-lying strata of compressible materials may have decisive effects on the surface structures specially, if there be means for the escape of water from them by pumping.

The applications of these ideas have been tested in some of the structures designed and constructed within the last two years and it has been found to be very satisfactory.

It is expected that structural engineers and designers of our land are conversant with this new outlook of their subject and a systematic and co-ordinated effort should be undertaken by the engineers and the applied physicists to determine the particulars for the type analysis of the underground soils. One could easily note that such analysis is of extreme importance in alluvial tracts where the soil characteristics are of varied nature and the calculations based on older concepts would lead to uneconomic procedures leading to uncertain results. The question of design of sub-base structures is getting more and more into prominence due to their need for cold storage, safe

deposit vaults and due to the urgent necessity created by the grave international situation for air raid shelters and one cannot overlook the need and urgency of these investigations as they form integral parts of the super-structures.

I shall just touch on brick building which is an ancient art and prehistoric in origin. The recent outlook on the subject would be interesting. Though the strength of bricks as derived from different types of clay and fired under different conditions has undergone considerable investigation, yet their surface resistivity is only being investigated quite recently. Here the technique of surface reflection, photometry and X-ray analysis has disclosed the porous nature of the surface layers and their effective resisting capacity against weather conditions. The moisture creeping factors of the bricks, by absorption through porous materials as sand plasters, have been the subject of investigation in a few laboratories and have disclosed considerable variation depending on the nature of grain structure and their transformation during the firing stage.

Metal Industry.

I shall now present before you the aspects of another industry which ordinarily appears to have very little to expect from applied physics. I mean the 'Industry of Metals'. Historically, it is more than a probability that the first metal industry was entirely one of applied physics. If as many archaeologists and historians believe, gold was man's first industrial metal, it was recognised by its colour, and its high specific gravity was used as a basis for its separation from the lighter rock-materials. The 'panning' operation is prehistoric in origin. It is, however, used prolifically even today, not only in the prospecting for gold but also for many other heavy minerals, for example, tungsten, uranium, copper, lead, thorium and a large number of sulphides. The operation is indeed based on the application of Stokes' law for the fall of sphere through a viscous medium. In its simplest form, the law states that under the action of gravity a sphere in a viscous medium fairly quickly acquires a constant velocity which is greater in a given medium, larger the sphere and the greater the difference in density between the sphere and the medium. In ore concentration, the pieces of rock are not spheres and the modification due to the shape has to be taken into consideration and has been investigated in some of the mining and ore separation institutes. The development of ore concentration machines, such as classifiers, jigs, shaking and riffled concentration tables, all take into account the modification of the above-mentioned law in its different modified forms. In the 'ore flotation' process, there is the application involving surface tension and adhesive phenomena. It is well known to mining profession that certain minerals, such as

sulphides, have greater adhesion for gas bubbles or for oil than for water. Most gangue rock, like silica, shows more adhesion for water and still more for acidified water. A mixture of sulphide particles and gas bubbles and gangue particles in a solution may result in the bubbles attaching themselves tenaciously to the sulphides until the average specific gravity of the ensemble is less than the solution and one gets the paradox—viz., that heavy minerals float. The preparation of froth, which helps to offer large surfaces for adhesion, has been the aim of these separators and various reagents for froth formation have been introduced from time to time. Quite recently this question of surface adhesion and surface layers has engaged the attention of physicists and the nature of ore surfaces are being investigated with ore microscopes and electron diffraction to elucidate the aspects of surfaces.

If one considers other ore concentration methods, one finds that they could be classified either as pneumatic, magnetic or electrostatic methods and all of them are essentially based on physical principles.

Turning our attention to the smelting operations, one finds that chemistry and physics work simultaneously in many phases. The separation of the slag from the metal is a purely physical process but chemical changes continue to function up to and after ingot pouring. In the furnace itself, there is continual heat exchange. The flow of gases under different temperature and reaction conditions is really regulated by physical laws. In the present practice of separation of flue dust from the blast furnace one finds an important application of applied physics. The magnitude of the operation would be realised from the fact that for each ton of pig iron, near about five tons of blast furnace gas have to be treated, containing flue dust which is eight to ten per cent of the weight of pig iron and the world production of pig iron for 1938 is more than 100 million tons. The device adopted for the purpose utilises first and second laws of motion as well as Stokes' law. The gas from the top of the blast furnace is allowed to enter a big chamber from the top and the velocity of the incoming gas flow is much reduced. It no longer can carry the same amount of dust suspended in the stream to be mechanically carried along with it. Most of the flue dust is projected to the bottom of the chamber which, after due sintering, is recharged into the blast furnace. Quite recently, when the laws relating to the eddy currents in air and stream-line shapes were being investigated for the design of zeppelin bodies, it attracted the attention of an American blast furnace designer and he utilised the principle by attaching a stationary stream-line shape in the path of the incoming high velocity blast furnace gas. The gas hits this stationary surface at a speed of about forty miles an hour and the shape is so designed that the speed is reduced to about four miles per hour and the eddy currents

are so far reduced that efficient separation of dust could be secured without any extra expenditure of energy. This new idea of stream-line has been utilised in the metallurgical operation. Further purification of the gas is effected by proper washing, where high surface energy of water particles in drop form acts as dust catchers. For still further purification electrostatic precipitation process is utilised. This electrostatic precipitation process is well known to applied physicists, as due to property of ions to act as nucleus for the attachment of fine materials whether in liquid or solid state. It is in principle the same as one finds in Wilson cloud chambers. The industrial use of this principle was first introduced by Sir Oliver Lodge and as a result, one finds the extensive application of the Lodge Cotterel process in the metallurgical industries to separate solid particles from smelter smoke either to make the smoke less objectionable or to recover the valuable flue dusts or both.

In the foundry, most of the operations are based on physical principles. One finds the temperature conditions suitable for casting operations, the nature of the fluid heads, the properties of surface wetting, the viscosity of the molten materials and the frictional flow of the hot liquids. All the above-mentioned factors are regulated by laws actually discovered by applied physicists and have been appropriated and have become integral part of the art of foundry.

The theoretical understanding of the nature of metals necessitates a close examination of their structures as well as the lattice constants. From the industrial point of view, the system iron-carbon is the basis of materials with remarkable properties. It is further well known that pure iron undergoes modification with temperature, in four successive stages α, β, γ, δ, as its temperature is raised from cold to its melting point. In reality, these fall under two categories, namely, body-centred and face-centred cubic lattice, and α, δ belong to the first type and γ belongs to the second. The β modification is not due to a change in the structure but indicates a change from the ferro-magnetic to the paramagnetic state. Now considering the alloys, pearlite is a combination of soft ferrite and hard cementite. One finds that the mechanical properties of unhardened steel could be attributed to this. Austenite is the solid solution of carbon atoms in iron and Martensite is the glass-hard constituent of steel formed by quenching. For a long time its character was a matter of difficulty to metallurgists and it has been recently noticed that this form is due to a composite alloy of a definite lattice form. The nature of 'prison-bar' steel in which the hard core, formed of chromium steel, happens to be surrounded by a sheath of mild steel, also indicates a peculiar structure formation due to heat-treatment. The mechanical properties of different structures formed by iron and carbon are now being correlated with the theoretical

ideas concerning the strength of materials. Theoretically the force required to break a test piece of steel or any other material in tension should be thousands of times larger than what is observed in practice. In trying to explain this anomaly, one has to consider two types of materials, namely, the brittle and the ductile. In the case of brittle material, the failure is due to the fact that it never gives way simultaneously across the whole of its section as one has to assume in theory. In fact, the parting of the crystal starts at one place and proceeds across it since this stress is due to local intensification at the edge of the growing crack. Most probably a sub-microscopic crack in the material is the starting point from which this tearing process begins. In fact Griffith has shown the existence of ultra-microscopic cracks formed on the surface of vitreous silica when one touches it with the fingers; though the material when freshly prepared possesses very great strength if it is kept uncontaminated from external agencies. A ductile material, on the other hand, yields to stress. It is distorted as if the atomic planes are able to slide over each other like a pack of cards. This type of plastic flow is well known from the behaviour of a single crystal of a metal in the form of a rod which could be pulled out to several times its length by a very small force. In a general way one finds why metals in a state of purity are ductile whereas complex structures such as intermetallic compounds are in most cases brittle. Atoms of a metal are not held together by bonds and so long as they are in close packing, many configurations may be possible. A distortion equivalent to a glide plane may take place without any serious disturbance of any one of the atoms. On the other hand, in a compound having complex pattern a large amount of movement has to take place before any re-arrangement of the pattern is possible. The material will not yield as no intermediate stages can occur and it will rather break than yield.

Now, considering the subject of other alloys, one finds by taking the metallic elements two by two, the possibility of building up a very large number of alloys. There is a striking difference between the structures produced by alloying two metals than those obtained by the combination of two elements. One could note that to form a chemical compound the products should be present in definite ratios whereas in a binary alloy, each phase constitutes an intermetallic structure extending over a range of composition. When examined by means of X-rays, each of these intermetallic phases is found to have its atoms arranged in a definite manner, some may be of the body-centred cubic, others may belong to the face-centred cubic types. In the chromium-aluminium system which has recently been worked out by the X-rays method, phases are so numerous that eleven successive notations are required to designate them.

The extent of the phases can be determined by the consideration of the free-energy of the alloys as obtained by X-ray experiments. The free-energy has to be minimum for the system to be in equilibrium.

$$F = U - T\phi$$

gives a relation between the free energy F, internal energy U, the temperature T, and the entropy ϕ, of the system. The limits of the various phases can be ascertained from a plot of the free-energy values of an intermetallic system against the composition. Even in the case of ternary system, this method has been extended by Bradley and Taylor who determined the phase boundaries of the iron-nickel-aluminium and other similar systems.

The question of phase patterns has been studied by Hume Rothery in considerable detail. His rule enunciates that in similar phase patterns, there is the same ratio of free electrons to atoms. As examples one could cite the case CuZn, a body-centred cubic structure, the ratio of electrons to atoms being 3·2 or 1·5. In brass this ratio is 1·62; though this rule has been found on close examination not to hold invariably, one may state that it is true in majority of cases. In order to have a general survey of the whole field of alloys, regarding their structure and properties, X-ray examination of the structure combined with consideration of free energy would lead to a better understanding of the nature of alloy-formation. Then, there is the question of the order and disorder change occurring in some of the alloys in the solid state when they are cooled from high to low temperature. X-ray analysis shows in the case of the alloys of copper and gold having Cu_3Au as formula, the arrangement of the face-centred cubic lattice is a random one at high temperature, the position being occupied without any regularity by the gold atoms. On slow cooling through a certain critical temperature, however, it is found that the atoms of gold travel to the cube corners and copper atoms to the face-centres and an orderly arrangement is set up. The iron-aluminium alloy of the composition, Fe_3Al, also exhibits this order and disorder change. One might conclude that since the ordering force can be destroyed by temperature, the forces are weak in alloys. Quite the reverse phenomenon has been observed in some alloy systems in which certain atoms pass out of the lattice with the fall of temperature and are disposed of by segregation. The ternary compound of iron-nickel-aluminium, Fe_3NiAl, is found to be homogeneous at high temperature but when slowly cooled it is found to contain isolated clots or groups of iron atoms. This alloy has been extremely useful as the constituent material for powerful permanent magnets.

A very interesting application of the properties of solid solution between two metals, one of which is in a liquid condition and other in a solid state, is technically known as the process of 'wetting'. The boundary layer, where such solution actually is formed, shows definite characteristics of an alloy formation. This process has been utilised in the manufacture of electric contacts when a tungsten disc is welded to a steel shank. An intermediary thin disc of copper is placed on the top of each steel shank, the tungsten disc being placed on the top of the copper. The ensemble is placed in a furnace with a hydrogen atmosphere until the copper melts. It is found that copper in a hydrogen atmosphere tends to wet both the tungsten and the steel. In fact under the temperature condition, namely, about 1100°C, an adherent of copper and steel is first formed on which the tungsten disc appears to float. With a slight rise in temperature, nearly about 1250°C, the wetting action of tungsten and copper begins. At first the tungsten disc moves about on the surface of the molten copper in an irregular fashion. But as soon as the process of solid solution of the tungsten in copper starts, discs of tungsten align themselves so that they remain centrally on the top of the molten liquid. This formation of the solid solution along with the effect of the capillary forces is also utilised in the manufacture of the welding electrode materials technically known as Elkonite. Powdered tungsten is pressed into briquets and moderately heated but not sufficiently to close the pores. It is then placed in molten copper in a hydrogen atmosphere. Capillary forces cause the copper to fill the pores even above the level of liquid copper, and on cooling one can get the electrode elements sufficiently hard and durable.

Another example of this type of alloy formation is found in the recent manufacture of cemented carbide tools for the machine tool industry. Tungsten carbide first obtained by Moissan is a very hard crystal. The crystal aggregations are porous in nature and brittle due to the existence of sub-microscopic cracks between them. Shrotter and Strauss tried to utilise this property of alloys and found that cobalt in a hydrogen atmosphere has the wetting property for the carbide. They compressed together powders of cobalt and tungsten carbide in a suitable mould and subjected them to moderate pressure. These were then put into an electric furnace with a reducing atmosphere and the temperature raised above the melting point of cobalt. They found that cobalt and tungsten carbide form a suitable matrix which retains the hardness quality of tungsten carbide intact. The material behaves more like diamond than like a metal. This has led also to the utilisation of the carbides of tantalum, titanum and molybdenum. These extremely hard crystals are soluble in each other in a wide variety of proportion at temperatures approaching their melting points. Even at 2000°C, the wetting properties and the

solubility are quite high. The solid solution indicates properties different from those of constituent carbides. Tungsten carbide with 6% cobalt bond will easily scratch sapphire and inferior only to diamond in hardness. One can have an idea of its hardness from the fact that whereas high speed steel with 18% tungsten contents has the Brinell number 800, that of the carbide with cobalt bond varies from 1400 to 2000. Its compressive strength is 500,000 ℔/sq. cm. It has negligible coefficient of expansion, practically half of invar steel and it is practically non-magnetic. Wide variety of application has been found for these carbides, namely, as substitute for diamond dies, for wire-drawing industry and for valves and valve seats of pumps. The only difficulty about the material happens to be that it is incapable of being machined and can be only worked with suitable grinding devices.

Now, I would like to present before you just another application of a technique, developed by applied physicist, opening up possibilities for a rapid quantitative determinations of the different ingredients of ferrous and non-ferrous alloys, I mean, spectroscopy. It is well known that as far back as early eighties of the last century Hartley first made a systematic study for the purpose. His work on beryllium and cerium indicated that when these elements are present in a matrix or body of other materials in small and decreasing quantities, its spectral lines gradually grow weaker and disappear in a definite order. Though Pollock and de Gramont demonstrated the utility of this technique, it remained ignored and forgotten till recently. The first lead in the subject was from the workers of the spectrographic laboratory of the National Bureau of Standards, U.S.A., in 1922, when Burns, Meggers, Kiess and Stimson showed that given proper attention, this method leads to fairly accurate results. W. Gerlach in Germany started a systematic investigation to enquire into the different factors necessary to get a correct interpretation of results. The present practice is based on his observations, namely, the adoption of an internal standard in the material to be investigated. A selected pair of lines, one from the major and the other from the minor constituent of the material in question at a definite ratio of the constituents, is selected. With the gradual diminution of the minor constituent the intensity of the line undergoes diminution in a definite fashion, and it is thus possible to arrive at a fair estimate of the percentage of the minor constituent. Furthermore, he found that there are homologous pair of lines in the spectra which have equal intensity under definite percentage ratios of the two elements. Within the last six years more than hundred workers are engaged in the subject and fairly large amount of literature has now been secured. Not only has the technique been efficiently adopted in many of the large metallurgical establishments in America and Europe but also

its importance has been instrumental in its adoption by the different ammunition and ordnance factories. In the routine analysis of the different constituent, for example, of the admiralty brasses in England, it has been found that 0·0007% of bismuth could be accurately estimated taking copper lines as the internal standard lines.

Electrical Power Industry.

I shall now consider 'Electrical Power Industry', an industry, little more than half a century old and is the direct outcome of physical research. The activity of Michael Faraday may be described as being repeatedly and continuously manifest on a large scale, in most varied manners, giving demonstrations of his law of electromagnetic induction. Magnetic fields in iron link electric current in coils, in generators, motors and solenoids in endless profusion, all over the world. The first electrical engineers were the great applied physicists,—Kelvin, Weber and others. The common electrical units volt, ampere, ohm, henry, farad, watt with one exception, are named after the renowned applied physicists.

I shall try to limit my subject by considering only the generation and distribution of power and exclude from it utilisation or conversion of electrical into other forms as light, heat, or electro-chemical processes. I shall treat, however, the field of communication which also transmits electrical power but at higher frequencies. In this restricted field I shall deal first with an aspect of physical investigation, which has come to the fore-front recently, viz., the 'Electric Discharge in Gases'. One meets this phenomenon practically at every point starting from the generation and leading up to the final utilisation circuits, sometimes serving very useful purpose and some other times as a disturbing factor leading to the failure of electrical circuits. The extent of the subject can be realised from the consideration, viz., that the present practice of power generation begins with the direct production of alternating current from about 11,000 to 33,000 volts. This voltage is then stepped up by transformers to a value suitable for transmission over short or long distances ranging from 22 to 287 kilovolts; this last value being used for transmission across a distance of 240 miles. For transmission system of intermediate high voltage, one finds it ranging from 2·2 KV to 6·6 KV for local distributions. For domestic and industrial utilisation circuits the voltage would be from 110 to 600 volts.

Let us begin with the alternating current generator with its exciter provided with a commutator and brushes for the generation of direct current to excite its field. Here one finds commutators depending for its proper functioning on the discharge between the brush and the receding commutator segment.

Further, one finds that the corona discharge in the minute air space between the insulated coil and the slots creating troublesome factors for the generator design. Next is the power switch, which functions by means of an arc between separating electrodes. In the oil circuit breaker, one finds the formation of the arc in a gas bubble formed by the decomposition of the oil. One has to alter the shape and disposition of the bubbles so that a short arc may be capable of performing its task of current interruption.

Let us now consider the transformer. In the design of its components, one has to reckon its different members, viz., the coils, core, the bushings and everywhere one finds devices whereby the baneful effects of discharge may be safeguarded.

In the transmission lines, as a serious disturbing factor one encounters the high voltage heavy current discharge-lightning. This has led to the provision of the lightning arrester, a device to produce protecting discharge to counteract the damaging effect of the lightning. Its spark-gap has to initiate the discharge and also to co-operate with other elements of the arrester in terminating the discharge after the passage of the lightning. Here the major tool for studying such problems is the cathode ray tube and the guiding element is the theory of ionisation in gases promulgated by the physicists. The modifications necessary in Townsend's theory to meet the conditions of high pressure and high breakdown voltage have been worked out by physicists but it was Rogowski, who after detailed series of investigations, indicated the need for the modifications. In the recent introduction of the 'protective tube' type arrester the spark gap is so ingeniously designed that the discharge passes down a tube made of fibre. The heat of the discharge decomposes some of the fibre into gas which passes through the discharge at such pressure and velocity as to extinguish the power arc at the instant when the current reaches the zero value. The flow of power through the conductor of the transmission lines is due to the magnetic and electric fields surrounding it. One has to avoid the formation of corona discharge from the conductors due to the overstressing of the air surrounding it. The nature of corona discharge has been the subject of study by applied physicists and engineers and still there remains a considerable amount of empiricism which could only be satisfactorily understood by their joint efforts.

It will be pointed out in the next section how different types of dielectrics are being requisitioned to avoid the harmful effect of these discharges. In the low tension circuits, the power fuses have to be designed to suppress arc formation. In a recent type, boric acid has been introduced to supply steam in small quantities sufficient to check the arc.

Considering the conversion of A.C. power to D.C., one finds the introduction of an arc formation device through the mercury

vapour. The mercury arc rectifiers have been rapidly replacing the dynamic type of machinery for conversion purposes in railway, industrial and electro-chemical processes. Here, the cathode spot in the mercury pool is kept in an excited state by the maintenance of a discharge to it from an auxiliary electrode or other main electrodes. In the 'ignitron' type of mercury arc tube, which is now finding industrial application, one finds a stationary rod of high resistivity material dipping into the mercury pool. It has been possible to produce at the junction, a concentration of electrical field and current flow, similar to that which occurs at separating contacts, leading to the formation of the cathode spot of an arc. In this tube the stability is maintained by placing the anode directly in the path of the vapour stream coming from the cathode spot. Tanberg observed that the vapour coming from the cathode spot at low pressures has an extraordinarily high momentum and energy corresponding to more than hundred volts. Such high velocity stream formation, though at first doubted by some, has now been confirmed and one can now understand it as due to multiple ionisation of the atoms.

Incidentally, one is led to consider the discharge phenomena in low pressure devices such as the 'thyratrons' and 'grid glow tubes'. Here the heated thermionic cathode provides the available electrons when a proper potential difference is applied, Here the formation of the plasma suggested by Langmuir satisfactorily accounts for the development of the discharge. In the low pressure gas tubes, there is a curious limit to the magnitude of the current that can pass through it. This sets a limiting value to the current depending on the pressure. When this value is exceeded, a kind of instability sets in, due to which, the discharge is sharply interrupted and re-established repeatedly in an erratic fashion. This has also been accounted for as due to a high degree of ionisation in the gas and it has been suggested that the effect is due to pumping of a high vacuum by the motion of the positive ions.

Let us next discuss in a general way some of these applications in power systems and find the problems common to them. Looking from this aspect one finds the initiation of the useful discharge, then their proper termination and finally the prevention of restarting after the current has attained zero value.

The initiation of discharge in switches and commutators takes place so simply and so spontaneously by the mere operation of separating contacts and the problem of terminating the discharge is frequently so difficult that one does not appreciate the useful function performed by it. If, however, one considers the fundamental aspect of Faraday's law, one finds that the very existence of the power system depends upon it. Without this device sudden high voltage will develop if the current is actually reduced to zero value quickly at the moment of separation

of the contacts. This moment is to be synchronised with the instant of the zero current value of the alternating power so that the electrostatic capacity of the system can absorb energy and thus avoid the dangerous high voltage formation. In general however, the capacity is so small that a very close synchronising would be necessary. Here the discharge in the gas comes as a safeguard rendering the separation of contacts at the desirable condition, effecting the safe interruption of the circuit at the following zero point of the current cycle.

There have been attempts to interrupt the circuits by dispensing with the separating contacts as in the case of the brush on commutators where the area of contact between the brush and segment, beginning from a maximum, approaches zero continuously as the segment moves away from the brush. Here even as theoretical treatment shows, there is the necessity for a close synchronisation with the course of the current and in practice, it is imperfect. A discharge is operative in the last conduction of current. It is thus manifest that in the case of all successful dark commutation, the final step of the interruption of the current is performed by the glow effect, however feeble that may be.

The next problem, viz., that of prevention of the restarting of discharge after the current value has fallen to zero is accomplished by setting up conditions such that either the positive column or the cathode spot or glow cathode cannot re-form themselves. For high voltage switches it is the positive column that has to be suppressed. Various means are provided to compel the positive column to have such a small section at the stage when the current has fallen to the zero value that its temperature and degree of ionisation fall to too low values for its re-establishment. Here one has to take into consideration the thermal ionisation theory of positive column worked out by K. T. Compton. The solid barriers with restraining magnetic field in the 'de-ion-grid' circuit breakers, the motion of the cold oil under pressure in the 'oil blast' breakers and the motion of cold air in 'gas blast' breakers, in the 'expulsion' type fuses and in 'gas blast switches' are the developments introduced in the field of electrical engineering practice.

In mercury arc rectifiers, ignitron, thyratron, grid glow tubes and low pressure gas discharge tubes, the absence of a cathode spot and insufficient voltage to maintain a glow cathode are generally utilised to terminate the discharge upon reversal of polarity.

The low gas pressure raises the voltage necessary to maintain the glow cathode, and so permits relatively high voltages to be handled. However, all these devices are subject to a type of failure. Occasionally and at random moments, in spite of the absence of conditions, which the present theory would regard as necessary, a cathode spot is formed at the moment of incorrect polarity and causes a short circuit in the device. The

statistical frequency of the occurrences of these 'back fires' or 'arc backs' is such as to indicate that possibly molecular aggregates are involved which may be impurities on the cathode surfaces or particles in Brownian movement through the gas coming in contact with the anode. It is also found that frequency of occurrences of these 'arc backs' increases rapidly when thirty or forty kilovolts are exceeded, so that the problem of this type of tube for very high voltages remains still unsolved. This phenomenon is of great technical importance, for on its successful solution rests the high voltage direct current power transmission which is the subject-matter of frequent discussions.

It is thus evident how 'the electrical conduction in gases' crops up at every point in an operating power system.

I shall next treat how the investigations about the nature of dielectrics is of extreme importance in maintaining the power systems. The problem of insulation plays an important rôle in the development of electrical power industry. Consequently, there has been a continuous flow of researches in the field of dielectrics:—gaseous, liquid and solid. Broadly speaking these researches are of two general types. The first is that of fundamental character and is carried out by applied physicists with a view to secure an insight into the mechanism which eventually may lead to an understanding of the useful properties of dielectrics and their behaviour when used as insulators. These properties are dielectric constant, electric conductivity, breakdown strength, dielectric loss and power-factor. The term 'dielectric behaviour' usually refers to the variation of these properties with frequency, temperature, voltage and composition. The second type of research is that in which efforts are made by engineers to develop directly improved materials and methods of insulation under the conditions of normal service by utilising any new discovery or suggestion made through researches of the first type.

I shall now present before you some of the recent fundamental researches in the field of dielectrics, particularly those which have a bearing on the application of dielectric properties to the problem of electrical insulation in power industry.

From the standpoint of insulation, the 'breakdown strength' of a dielectric is worthy of our first consideration. Persistent efforts particularly those using cathode ray oscillograph and other methods for following short time phenomenon have, however, resulted in a well-developed theory which has been universally accepted to explain the mechanism resulting in the electric breakdown of gases. The basis of this theory is the Townsend picture of ionisation by collision for which important modifications, due principally to the part played by the positive ion in the final spark over, have been necessary. Rogowsky and Wallraff have examined the question whether the breakdown over large gaps are due to local high stresses caused by

space charges or to ionic bombardment of the cathode. They have concluded that the beginning of breakdown must be attributed to the ionising action of the positive ions. W. F. Bowls has reported that the secondary ionising mechanism necessary for the increased production of electrons requisite to spark over is not due to positive ions in the gas, but to the liberation of new electrons, by the bombardment of the positive ions in the gas on the cathode.

Theories of dielectric strength and breakdown of liquids take a wide range. The Schumann-Nikuradse theory of breakdown ties in the current voltage characteristic in much the same manner as now accepted for gases, and accounts the failure as an internal collision ionisation phenomenon. Kopplemann and Gemant invoke an electrode layer under high stress due to space charge acting on a layer of absorbed gas, thus creating gas pockets or filaments leading to gaseous ionisation and breakdown. Pure electric breakdown is apparently due to electric collision-ionisation and is recognised only in the purest liquids. Thermal breakdown on the other hand, due to the liberation of gases by heating, in impure liquids, is also evident in many cases.

The breakdown behaviour of commercial insulating oils is of special interest. It has been found that their electric strength increases with their degree of purity.

Large amount of important work has appeared concerning breakdown in solids. In this connection, the conclusion of S. Whitehead, supported by Von Hippel, is worthy of note. According to these authors, electric breakdown in solids is to be understood as an electron collision phenomenon originating through an excess number of electrons in the lattice. The frictional losses of these electrons are due to the oscillations which they excite by electrostatic influence in passing the ions of the lattice. This friction may be expressed as a function of the electron energy. Beyond the maximum value of this function, the frictional retarded motion of the electrons passes over into an accelerated movement down the potential gradient. Electric breakdown thus occurs primarily through the setting up of electron collision ionisation channels. The directional breakdown noted in crystals is a result of the shape of the excitation function, which is dependent upon the direction of the path with reference to the lattice and also upon the high gradients that result from the accumulations of space charge.

It has been found that the dielectric strength of solid insulators decreases markedly with increase of frequency.

Researches have been conducted by several physicists to study the process leading from initial ionisation to self-supporting spark or arc discharge. These studies are of special interest because of their obvious bearing on the mechanism of various protective equipments used in power industry.

Incidentally, it may be mentioned here that the dielectric losses in oils in the low-frequency range, are commonly due to ionic conduction. As the frequency is raised through the radio range, dipolar losses begin to appear. The variation of power-factor or of dielectric constant with frequency is not sharp. This want of sharpness has been attributed to the presence of several constituents having different values of ionic mobilities and dipolar properties.

The problem of 'stability' in oils has engaged the attention of physicists for some time. They have divided the oils into two groups. In one group are oils of the transformer type which are used for submersion and in which the important properties are continued fluidity and dielectric strength. In the other group are the oils used as impregnants, as found principally in capacitors and high-voltage cables. In the field of transformer oils, the action of oils on metals has been investigated. It has been found that copper gives the largest quantity of sludge. A relation has been established between the percentage of aromatic constituents in the oil, the frequency of the applied voltage and the amount of sludge formed. It is suggested that to prevent corrosion by insulating oil, copper should be protected by a layer of another metal, tin and lead being found useful for this purpose. It is stated that acid is not a determining factor in corrosion and water has no unfavourable influence on the dielectric loss of transformer oils. Stability in impregnating oils has been a problem for years. Instability is the word used to describe the slow deterioration of high-voltage impregnated paper cables. It has generally been assumed that the causes are to be sought in the impregnating oil. It has been found further that oils having a large ratio of dielectric constant to density show rapid deterioration under oxidation. Gaseous ionisation is known to be an important deteriorating agent probably through changes in the oil due to ionic bombardment. It is not always possible, however, to account for gas pockets or bubbles in well-impregnated insulation.

The impregnated paper power cable continues to receive intense study. The chief problems are the reduction in wall thickness through increased dielectric strength, permanence or stability as inherent in the properties of the basic materials and in the suppression of gaseous ionisation.

G. B. Shanklin has found that there is considerable improvement of power factor of impregnated paper, treated with carbon dioxide during drying and impregnating process. Though lead is not an insulating material, the lead sheath is a vital element in preserving the inherent properties of cable insulation. Improvements of lead sheathing technique are progressing. Especially noteworthy are the vacuum press (Atkinson and McKnight) for limiting oxidation and gas inclusions during

leading, the hydrogen press (Shankling) for similar purposes and other measures for greater uniformity of the resulting metal.

Physical structure and dielectric loss of impregnated paper, as related to the amount of contained air and under changes of voltage, temperature, frequency and pressure, are reported by P. Junius. The conclusions are, that the shape of the power-factor voltage curves at different temperatures changes very little in a dielectric containing large amounts of air. On the other hand, the shape of these curves varies noticeably in well-impregnated cable. In the latter case the change of power factor due to temperature change may be much steeper than that for a cable containing air. An increase of pressure by one atmosphere is sufficient to cause a flat loss-curve in a cable which contains much air.

The pressure principle has also received extensive trial. The advantages of pressure on the dielectric are increased dielectric strength and the suppression of internal gas voids. The problem is therefore to ascertain the most reliable method of applying the pressure either by an outside gas or liquid medium or by hydrostatic pressure inside the cable and also the proper ranges of pressures for securing best results. It has been found that oil-filled cable for the higher ranges of voltage is very suitable.

C. A. Grover discusses the feeding of oil to an oil-filled cable, with a detailed development of a method which permits a computation of pressure conditions resulting from temperature variations through the cable and at the feeding points due to load variations. The Callender Company has developed a single conductor impregnated gas-pressure cable with rating of 200 KV. conductor cross-section, 420 sq. mm.; thickness of insulation 23·6 mm. A small space is left between the impregnated paper insulation and the lead sheath. This space is filled after assembly with dry nitrogen at 14 atmospheres excess pressure, the lead sheath being heavily reinforced with copper tapes.

The causes of instability and deterioration continue to occupy our chief attention. In recent years we appear to have passed through a series of modifications in our ideas of the principal causes of cable deterioration. We have noted as chief suspect in successive periods, high inherent power-factor and loss, gaseous ionisation, wax-formation and oxidation. At the moment we appear to be leaving the oxidation period and reverting to that of gaseous ionisation through new methods for studying free gas spaces in the cable.

Careful studies are reported of the stress at which gaseous ionisation begins and as related to different grades of paper. It is stated that both nitrogen and carbon dioxide are the best gases.

Of outstanding interest during the past few years is the progress in the development of new insulating materials of both plastic and ceramic types. Especially noteworthy is the range of physical properties available in several new plastic materials.

Conspicuous among the new plastics are the various polymerised forms of monomeric styrol. Several investigations have been carried out on the applications of styrene. Of special interest is the control of the induction period of polymerisation and the rate at which the latter takes place. This has permitted the pre-impregnation of paper tape with the monomer with certain admixtures, preventing the sticking of the tape in rolls, polymerisation being effected after application, for example, in a cable joint. The possible use of styrene instead of oil as a saturant for high-voltage paper cable has been suggested.

Improvements have also been made in the composition of artificial rubber which is found to possess a number of advantages over natural rubber. The vulcanised synthetic rubber is replacing natural rubber in high-voltage rubber-insulated conductors, in water-proof insulated wiring and in many other cases. Thermoplastic synthetic rubber materials are replacing fibrous insulating materials in a number of services.

Numerous classes of synthetic resins have also been developed. Since November 1934 about one thousand new trade names for resin offered as insulation have appeared.

Many new ceramic materials have also appeared. New developments in ceramic for insulation are confirmed principally to those for radio service. All these materials have been introduced as insulators to meet the demand for low dielectric losses in the high-frequency range.

I shall now relate to you just a few items of interest in the field of communication. The rapid expansion of Wire and Radio Communication Systems after the close of the World War in 1918 has necessitated the development of various communication industries utilising the results of fundamental researches. Limitation of space does not permit me to deal with more than a few of the researches which have been of wide application. In transmission of telegraph signals over circuit, the speed of signalling in bands or words per minute varies inversely as the product of total capacitance and total resistance of the circuit. The long cable circuit, specially of submarine type, has large capacitance and large resistance and thereby the speed of signalling is reduced to 50 to 60 words per minute. The effect of this inherent capacitance could be overcome by increasing the circuit inductance, that is, by 'loading' the circuit.

The case of transmission in message and broadcast programme telephony is more complicated since it involves a large frequency band (i.e. 100–4,000 c.p.s. for message and 31–10,000 for broadcast programmes. It follows from theoretical consi-

derations that the product of circuit capacitance and resistance (C . R) must be equal to the product of circuit inductance and leakance (L . G) in order to have the transmission loss and the velocity of propagation same at all frequencies in the band thereby eliminating the frequency and phase distortions. In trunk cable circuits this can be roughly realised in practice by inductance (L) either by insertion of loading coils wound over magnetic material cores at intervals or by wrapping magnetic material tapes helically over the conductors.

The requirements of a loading coil are (1) the permeability should be high and remain constant for all frequencies; (2) eddy current and hysteresis losses should be negligible for all frequencies in the band; (3) leakage or superimposed D.C. should not alter the working point on the magnetisation curve appreciably; (4) the ratio of resistance to inductance of the coil should be very small for all frequencies; and (5) coil size should be as small as possible. For the continuous loading, the magnetic material tape should be very thin about 1/10 of a mm. and at the same time the increase of inductance should be adequate for the purposes, thus requiring a material which has a high permeability for currents of the order circulating in telephone circuits. At the same time the requirements (2), (3) and (4) mentioned above for loading coils must also be satisfied.

Electrolytically deposited iron in the form of dust has served as core material of the loading coils till recent years, while 78·5-permalloy tape has replaced iron tape for continuous loading since about two decades. There has been still sufficient room for improvement in both. The audio transformer used in radio equipment or connected between transmission line and programme repeater requires its response characteristic to be strictly uniform from 30 to 10,000 c.p.s. or even more. For cores and pole pieces in loudspeakers it is necessary to have high permeability in the range of flux densities between 10,000 and 20,000 gausses. Use of iron dust in audio transformer and of stalloy in loudspeaker fails to give the desired performance.

The study of the magnetic properties of certain alloys of iron, nickel and cobalt has revolutionised the design of loading arrangement in telegraph and telephone transmission systems, of audio transformers and retardation coils in communication equipments and of cores and pole-pieces in loudspeakers.

The properties of these alloys were discovered through exhaustive researches in which all possible combination of three metals—iron, nickel and cobalt—were explored. The factors which contribute to the properties of the alloy the purity of the elements used in the alloy, their preparation and the heat treatment.

The permalloy series includes nickel-iron alloys containing 30 to 95% of nickel. Remarkable variations in magnetic

properties with composition are revealed in this series of alloys. The initial and maximum permeabilities of 45-permalloy under standard practice of heat-treatment are 2,700 and 23,000 respectively. For cores requiring high permeability for flux densities between 10,000 and 15,000 gausses, this alloy is specially useful. The design of cores and pole-pieces for loud-speakers may be done with advantage with this alloy. In 78·5-permalloy, quenching gives a higher maximum permeability than in any other permalloy and initial and maximum permeabilities of 10,000 and 105,000 respectively are developed. The hysteresis loss and the coercive force of quenched 78·5-permalloy are minimum. This alloy is suitable for continuous loading of telegraph and telephone cables. The negligible magnetic losses, non-alteration of magnetic properties with D.C., higher core permeability and material decrease in the size of loading coils have led to the use of improved 80-permalloy dust core in them. For audio transformers, both 3·8–78·5-permalloy and 3·8–80-Mo-permalloy have been used and uniform response from 30 to 16,000 c.p.s. have been obtained.

Perminvars are alloys of nickel, iron and cobalt. The constancy of permeability and extremely low hysteresis loss makes 45·25-perminvar the right material for applications where distortion and energy loss are detrimental to high grade transmission. Since the discovery of the properties of perminvars, they have been used for chokes, audio and carrier frequency transformers, filter elements, etc., in equipments designed for high grade transmission. It is specially suitable for continuous loading of long submarine cable circuits for voice-frequency or carrier frequency operation.

Permendurs are alloys of iron and cobalt. The principal magnetic property of these alloys is high permeability in the range of flux densities between 10,000 and 25,000 gausses. Permendurs have been applied with success to the design of cores and pole-pieces in loudspeakers and certain special types of telephone receiver where their principal magnetic property has been utilised to the best advantage.

One of the most recent advancements in communication art has been the wide band transmission on circuit between two stations to give as many as 240 or 320 high grade telephone channels simultaneously by employing the frequency range ·06–1·024 Mc./s. or 0·5–2·1 Mc./s. depending upon the number of channels. Such multi-channel carrier systems are worked on coaxial cables on four-wire principle. If one and the same coaxial cable is used, two coaxial circuits are provided therein, one of them for transmission of bands in one direction and another for transmsision of bands in the reverse direction. If two separate coaxial cables are used for two directions, then each cable consists of one coaxial circuit only.

The coaxial cable circuit is much more suitable medium than open-wire and ordinary cable circuits for transmission of higher frequencies as mentioned above. Among the various advantages like ease in construction and maintenance, lower cross-talk level, etc., may be mentioned the lower transmission loss of pronounced stability. Loss in a transmission circuit is made up of (*a*) conductor loss, (*b*) insulator loss, and (*c*) radiation loss. In coaxial cable circuit, the radiation loss is negligible since the unearthed central conductor is entirely surrounded by earthed concentric conductor, and insulator loss is considerably less and further much more stable. The other factors remaining constant, the reduction and stability of loss depend entirely upon the type of insulator used.

When the system was first launched into the field, the coaxial cable had its central copper conductor supported at intervals of ¾ inch by hard rubber discs. In recent years, improvement in reduction of insulator loss and obtaining higher stability has been realised by use of polystyrol compounded with rubber or balata under trade name of 'Superstyrex'. Earliest reference to the electrical characteristics of the solid polystyrol is contained in a patent by Matthews in 1913 where the inventor proposes to replace hard rubber, celluloid, vulcanite, ebonite, glass, wood by polystyrol or polystyrol compounded with rubber. The International Telephone and Telegraph Laboratories, Ltd., subsequently took up the studies of polystyrol with particular regard to its application to the insulation of cables. From this study a number of patents evolved dating from 1929 down to the present day dealing first with combinations of polystyrol with rubber, balata, etc., of a thermoplastic nature suitable for extrusion but later with other processes and applications.

The permittivity of polystyrol is low (2·2 to 2·6), and its insulation resistance under A.C. or D.C. voltages is very high even at high temperatures or under high humidity. The material retains its high grade insulating properties even after immersion in water and this fact has led to its use as submarine cable insulator replacing guttapercha. The inclusion of chemical impurities in the material during manufacture appreciably affects the conductance of the material to the extent that power-factor varies from ·0001 to ·0006. While dielectric losses of this order may, from some points of view, be neglected, there are other electrical insulation problems of the type involved here in which the increment of even small dielectric losses are of importance.

Commercial utilisation till recent years has been hampered by the absence of supplies of monostyrol, the basic material, on a commercial scale. This is now available from chemical plants in several countries.

In addition to the application in coaxial cable referred to above, widespread application of the material to condensers, moulded castings, etc., has already begun. Lacquers have been developed and there is a tendency to use polystyrol for all cases where the highest grade of insulation is in demand.

The outstanding problem is that of employing a hard, glass-like material in situations where toughness, flexibility, etc., are required. This necessitates engineering work of a high order, firstly, to design the form of insulation of the cable, apparatus or machine in such a way that a variety of 'Superstyrex' may be manufactured to suit; secondly, to design a suitable variety of 'Superstyrex'. In the latter problem, little or no reliance can be placed on plasticisers. In general, plasticisers are considered as impurities particularly in applications involving H.F. alternating fields.

I would now turn to the most important branch of communication industries, namely, thermionic vacuum tube industry and consider some of the problems associated with the design and manufacture of modern receiving tubes. During the last fifteen years, the efforts of tube manufactures all over the world have been concentrated to increasing the performance of receiving tubes by evolving several new types for special purposes and by improving existing types by modifications in the mechanical design, improvement in electrodes and cathodes, better arrangement of insulating and spacing the electrodes and exhaustive studies on 'gas properties' of electrode materials and on 'getter' materials Some new contrivances like 'grid-winding machine' have to be invented. A study of the causes and methods of reducing 'noise' has also received due attention. Developments in radio receiver design are continually demanding new types of tube and modifications to existing ones. The manufacturing plant must therefore be sufficiently flexible to allow changes to be made rapidly.

A close control has to be made of the mechanical properties of materials used for components. The manufacturer is limited in his choice of metals for electrodes to only those which have high melting-points and low vapour pressures even at temperatures as high as 1000–1100° C, the temperature reached by the electrodes during pumping operation. Nickel is invariably employed as the plate material and for electrode support wires. It is not sufficiently rigid for the winding wires of grids for which alloys containing molybdenum or nickel-manganese alloys are used. Iron is sometimes used as plate material for screen-grid tubes in which the anode is in the form of two plates.

The manufacture of 'grids', which a few years ago, was an extremely laborious process, is now carried out on special machines called 'Grid-winding machines' capable of winding as many as 200 to 1,000 grids per hour. The grids are wound

in lengths of about 60 cm. and subsequently cut into the required lengths. By operation of a cam on the machine, gap or gaps can be introduced in the winding of grids which are necessary for a variable-μ characteristic. It will be realised that uniform mechanical properties of the wire for winding grids (which are of course always slightly larger than the mandrels on which they are finally pressed or stretched) are very essential. Also the strain introduced during final shaping must be small, otherwise distortion will occur on heating.

Equally important are the 'gas properties' of the electrode materials. The term 'gas properties' includes not only the amount of gas which may be included in the metal but also the capacity of the metal to re-adsorb gas on its surface. This last factor is in some cases much more important than the first. Investigations of the sources of gas in receiving tubes have revealed that carbon dioxide adsorbed by the electrodes during decomposition of the barium-strontium carbonates on the cathode is much more difficult to remove than the residual gas existing in the metal. The nature of the surface of the electrodes has an enormous effect on this adsorption.

For insulating and spacing the electrodes from one another, mica is generally employed. It is decidedly superior to other possible materials as it is mechanically strong even in very thin sheets, can be formed into flat plates of any desired shape with great accuracy and has just sufficient flexibility to allow the electrode support wires to slide easily through holes without becoming jammed. For temperatures up to 500°C, the best quality ruby clear mica has good insulating properties, is chemically stable and evolves little gas. Above this temperature, mica rapidly decomposes with the liberation of water vapour, one of the most harmful gases in a tube and electrolyses. In tubes where still higher temperatures are reached, alumina, magnesia or steatite, pressed from powdered material to the required shape and sintered at 1500°–1800°C, are employed.

One of the most important features of the modern receiving tube is its highly efficient oxide-coated cathode. The various types of emitters that have at various times been used may be classed as follows:—(*a*) Clean-metal emitters; (*b*) contaminated-metal emitters, and (*c*) oxide emitters. In early days, the desirable features in an emitter were only thermionic emission, mechanical strength and long life. Emission efficiency was not considered a serious problem. All the early tubes were of directly heated filament type. Tungsten suited their requirements very well indeed and may be cited as an instance of clean-metal emitters. Later on, in order to improve the mechanical properties of the tungsten, thorium oxide was added to the tungsten oxide during the manufacture of the tungsten, about 0·7% thoria being obtained in the final wire. Langmuir showed that thoriated tungsten had a considerably higher

thermionic emission than tungsten at the same temperature. Thorium obtained by reduction of the thorium oxide diffuses into the surface of the tungsten and at temperatures where bulk thorium could not exist, a mono-atomic layer adheres to the tungsten surface with the result that its work function is reduced. Thorium-on-tungsten is an instance of next class. The discovery that the work function of a metal was reduced when a layer of atoms of another electro-positive metal was present on its surface led to much work on caesium-oxygen-on-tungsten emitter. The more electro-positive the contaminating metal is, the more the work function is reduced. A still greater reduction in work function is obtained when the contaminating film consists first of a layer of electro-negative atoms such as oxygen and then a layer of electro-positive atoms. The most efficient form of such type of surface yet developed is caesium-on-oxygen-on-tungsten which is another instance of contaminated-metal emitter. The demand for highly efficient cathodes which were inexpensive to operate directed the attention of the manufacturers on the oxide emitters. As the emitter becomes more efficient, the degree of vacuum becomes increasingly important because of the 'poisoning' effect of gas on the emitter. Hence a great deal of improvement in the high-vacuum technique had to be achieved. The oxide cathodes are generally produced in the evacuated bulb, and a large quantity of gas has to be removed from the valve before any activation of the cathodes can be attempted.

In indirectly heated types, the cathode is generally a hollow tube of circular, oval or rectangular section which is heated by a filament inside the cathode and insulated from it. The core material is generally tungsten. Since the heater wire normally works at several hundred degrees above that of the cathode surface, it is essential for the wire to have a high melting-point. Another form of core now being used consists of molybdenum-tungsten alloy which has many advantages, since it retains the ductility associated with the molybdenum and yet has a melting-point well above that of molybdenum and a vapour pressure which is negligible below 1750° C. The insulating material consists of a refractory such as alumina which is sprayed on the heater. Magnesia has also been tried as an insulating coating but has been found unsatisfactory for several reasons.

A 'getter' is used for maintaining the vacuum in a tube after it has been sealed off. The alkaline earths, the alkali metals and magnesium are common getters. An alloy of barium and magnesium and barium are mostly used at the present moment.

If the metal of which the getter is composed is relatively stable in air, it is welded to a metal disc and dispersed by 'high frequency heating' of the disc. If the metal is an unstable one like barium, it is packed inside a closed container before welding.

The high vapour pressure generated on heating is sufficient to burst open the container and the metal is dispersed. For avoiding any deposits over the electrode bonding system, the getter dispersal is usually directed towards the bulb wall by suitable design of container. When very high inter-electrode insulations are desirable for special tubes, alkaline-earth oxide getter is preferred. This is sprayed on to a metal disc in the form of cathode coating and decomposed by high-frequency heating of the oxides. The oxides act as getters when cold. It will be noted that since the emitting cathode itself is a mixture of alkaline-earth oxides, it will also adsorb gas in the active state.

Refrigeration Industry.

I shall next take up 'Refrigeration Industry'. Refrigeration was born in the laboratory. It remained for a long time confined within the laboratory to be used in various physical investigations. The mechanism and the laws governing it, have been the subject of studies for physicists for more than a century. Even at present the production of low temperatures and the study of the properties of materials under extreme low temperature conditions form the subject of research in special Cryogenic laboratories.

The first industrial application was the production of ice. The first commercial refrigerant was the ammonia gas which on compression liquefies and the quick evaporation of the liquid results in reduction of temperature, so that heat is abstracted from the container sufficient to freeze the water in it. Physical investigations disclosed a number of other substances such as sulphur dioxide, ethyl chloride, etc., which could be used as refrigerants. One now finds their industrial use all over the world.

It is, however, well known that the above-mentioned mechanism was not capable of being utilised for obtaining sufficiently low temperatures. The search for new principles and new methods were being vigorously pursued and this has led to the means of securing extremely low temperatures. I would like to bring before you, though they are well known, some of the basic ideas underlying these processes whose proper understanding has contributed to the immense growth of the industry. Let us start from well-known properties of gas, namely, that if a gas is allowed to expand freely at high pressures, the molecules would separate and some work has to be done. It is the kinetic energy of the molecules which supplies the energy and accordingly one finds the lowering of temperature. This is evidently converted into potential energy represented by a change in the electro-magnetic stress in the molecules. The molecules are not only in constant motion but are in continual collision with one another and these collisions also result in electromagnetic stresses being set up. If it could be imagined that at a particular

instant of time all the molecules in a state of collision are stationary, one would certainly get the maximum electromagnetic stress and for that moment whole of the kinetic energy would be reduced to zero. The gas would be at the absolute zero of temperature. At the next instant a repulsion would be set up among the molecules and this would lead to a rise in the kinetic energy. Such exceptional conditions do not arise in practice and one finds an average condition. But this leads to an understanding of the fact that under certain conditions, a gas even on expansion has a tendency to get heated. So there are two effects in every gas—one leading to cooling depending on the degree of separation of molecules and another to heating depending on collisions and this would increase with temperature. One thus expects in all gases at a sufficiently high temperature the net effect of expansion to be a rise in temperature. At a certain temperature, namely, the inversion temperature, there is no change and below it a lowering in temperature on expansion. The full realisation of this phenomenon leads to the proper application of the mechanism to secure low temperature.

Let us take the case of air for which the Joule-Thomson effect is by no means small. Thus at 0° C air is cooled 0·29 degree centigrade for a fall of pressure of one atmosphere. for a fall in pressure of 200 atmospheres the cooling effect is about 40° C. Roughly speaking if the molecules are about two diameters apart and are then separated so as to be ten diameters apart, they lose about 15% of their kinetic energy. It would appear therefore that to liquefy air which has a boiling point of about 194° C or 79° K, a fall in pressure of 1,000 atmospheres would be required. However, in practice, expansion to atmosphere pressure is rare, for while the cooling produced depends on the fall in pressure, the work done in compressing a gas is proportional approximately to the logarithm of the ratio of air pressures. Again, liquefaction at ordinary temperature is impossible, for the air must be below the so-called critical point, which for air is 132° K. This therefore means that some arrangement would be required for a preliminary lowering of temperature. This device, known as 'Cold regenerator' or 'Heat exchange', was developed soon after the discovery of Joule-Thomson Effect. In general this consists of two series of closed tubes, through one of which the compressed gas proceeds on its way to the expansion nozzle, and through another, in close thermal contact with the first, the relatively cold expanded gas returns. In fact the realisation of the Joule-Thomson Effect under proper conditions led Linde and Hampson to design and build machines for liquefaction of air for industrial purposes.

There is yet another aspect of the same phenomenon. A compressed gas would get cooled when by expansion in an engine, it does external work. The bombardment of the rapidly moving molecules of gas on the piston constitutes the pressure

and as the piston moves and does work, some of the kinetic energy of the molecules is transformed into external work. The gas on expansion would have lower temperature. The gas to be liquefied is compressed and cooled by water or air. Part of it then passes into an engine, does work by expansion and is thereby cooled. It then passes into a condenser to act as heat exchange mechanism to cool another part of the gas from the compressor below its critical temperature. To liquefy air, the compressed gas in the engine should be at a very low temperature at about 120° C. This process has been commercially developed by Claude. It is rather interesting to note that Kapitza adopted this method for the liquefaction of helium. The mechanism was capable of reaching below 10° K.

It would not be out of place here to present before you how other properties of material are being utilised for obtaining extremely low temperatures. By the expansion of a compressed gas with or without external work being done, coupled with the cooling due to evaporation of the resulting liquid it has been possible to obtain temperature less than 1° K. While it is most improbable that the absolute zero of temperature can ever be reached, advantage has been taken of the magnetic properties of matter to approach it very closely. In general the magnetic dipoles get arranged in orderly fashion at comparatively, high temperatures but there are a few substances, such as iron-aluminium alum, in which random orientations exist at very low temperatures. When these substances are at the lowest temperature attainable by the methods previously described and a magnetic field is created, the field controls the dipole direction and heat is developed. This heat is slowly absorbed by the surrounding substances and when the low temperature is restored, the magnetic field is removed. The dipoles get back to some extent into the disordered condition again and consequently the temperature is lowered. In this way a temperature as low as 0·003° K has been attained.

The need for the refrigeration as a direct agent has largely been utilised for the purpose of cold storage, where rooms are cooled with the help of a bank of coils through which brine is circulated. The brine is usually cooled previous to its circulation by means of suitable refrigerating chamber. Cold storage has been developed within the last few years to such magnitudes that one could find now the refrigerated space in ships bringing food to Great Britain alone amounting to not less than hundred million cubic feet. Today there are single ships having refrigerated space of over half a million cu.ft. capacity and capable of carrying cargoes amounting to 5,000 tons. The capacity of the public stores in Great Britain alone in 1937 amounts to 50,000,000 cu.ft. The annual output of artificial ice is of the order of one and a half million tons and the fishing industry of Great Britain uses more than 700,000 tons of ice annually.

Besides the ordinary ice, one finds now the industry of solid carbon dioxide coming to the forefront. It is rather wonderful that a product, which was used only in the physical laboratories in 1926, has become in bare fourteen years' time an important commodity. There are at present in America more than sixty plants for the production of solid carbon dioxide and in other parts of the world, namely, in England, Germany, France, Australia, Japan, South America, Africa, India and Canada, the number of such plants is more than eighty. The properties of solid carbon dioxide are sufficiently unusual to suggest a host of applications. It sublimes directly from the solid to the gaseous state at pressures below 5·11 atmosphere. At one atmosphere the temperature of sublimation is $-78{\cdot}5°$ C. At 5·11 atmosphere pressure the triple point occurs at $-56{\cdot}6°$ C. The liquid cannot exist at temperatures below that of the triple point nor at pressures below 5·11 atmosphere. Further its critical point is at 31° C at 75·79 atmosphere pressure so that the gas can never be liquefied above 31° C, i.e. above the critical temperature and at high pressure, gas and solid are in equilibrium. It has no true melting point and the latent heat of sublimation at the ordinary atmospheric pressure at a temperature $-78{\cdot}5°$ C amounts to 136·9 calories per grm. Its high specific gravity coupled with its high latent heat materially reduces the space required for storing a given amount of cooling effect. At present it finds the largest applications in the food industries especially the ice-cream industries of the United States. It has found wide application as preservative for meat and fishes as well as eggs. Only point against it is that it is still ten times dearer than ordinary ice even in large commercial productions.

The cold storage industry has utilised a number of other devices such as humidity recorders, temperature recorders, pressure recorders, ozonisers, all of them products of investigation of applied physicists.

I shall now bring before you the question of air-conditioning and air-hygiene, getting into prominence by the introduction of refrigeration in its various aspects. At first it was limited only to big establishments such as public halls, auditoriums, cinema houses, and air-conditioned trains. But now its size is reduced to that of a household appliance and single room conditioners are at present marketable commodities.

I shall now relate to you some of the indirect applications of this industry. When the demands for the liberal supply of oxygen for medical and industrial purposes first arose, they were met by chemical processes, namely, the oxidation and deoxidation of barium oxide. But soon after the introduction of the air liquefaction processes of Linde and Hampson, oxygen and nitrogen are separated by processes of rectification from liquid air. In 1938 thousand million cu.ft. of oxygen has been consumed

in the welding industry. Today single plants are in operation which produce as much as 80 tons of nitrogen per day to be used in the manufacture of cynamide, the nitrogeneous fertiliser formed by passing nitrogen gas over heated calcium carbide. For the manufacture of synthetic ammonia considerable quantity of nitrogen is being daily utilised. In 1894 Rayleigh and Ramsay discovered argon as a constituent of our atmosphere and now the lamp industry alone consumes ten million cu.ft. of argon extracted from air every year and at present one thousand million lamps filled with argon are manufactured by the different lamp industries of the world. The annual saving in the light bills of the world exceed many million pounds. Neon is also another constituent of the atmosphere which is extracted from liquid air. Its use in the vapour discharge lamp for advertising purposes and for beacon lights is increasing every year. These results could not have been obtained without the refrigerating machineries whose principles and mode of operations have entirely been developed by the physicists, pure and applied.

Automobile Industry.

As an example of application of applied physics to industry I shall next choose 'Automobile Industry'. This is less than half-a-century old and it could not have been earlier. Let us now consider how different branches of applied physics have contributed to the development of this industry.

Firstly, one finds 'Properties of Materials' ranging from the cast iron to the varied types of alloy-steel, aluminium and its alloy, required to form the different members of the engine and its power transmitting mechanism. Steel is required having properties to stand high stresses under high temperature conditions. Here not only high tensile strength but also high torsional rigidity and hardness to resist friction and wear under extreme conditions are necessary. One has also to know how far one could exceed the elastic limits of its running parts to provide against accidents. One should also acquaint himself with the effects of heat treatment of these different classes of materials to impart to them the required properties to serve the needs of the machine. The determination of hardness characteristic is performed by the application of Hertz's theory of impact in the different testing machines evolved for the purpose. In its body building, one must know how far one should exceed the elastic limits under different conditions and to attain the desired plastic deformations. The general knowledge of kinetics is essential for the proper assemblage of its members and their linking, so that one could secure the desired motion and speed under different conditions. One should not disregard the lubricants. The theoretical interpretation of the action of lubricants awaited the work of Osborne Reynolds in 1886, in

which he considered the lubricating film to be moving between two parallel plane surfaces. Applying the relations of classical hydrodynamics, he deduced the equation underlying the theory of 'thick film lubrication'. The specific case of the journal bearing was first satisfactorily treated by Sommerfeld with the assumptions of liquid incompressibility, absence of turbulence and independence of viscosity on pressure and rate of shear. He considered the minimum film thickness for a given clearance and showed that it increases monotonically with increasing liquid viscosity, journal speed and decreasing load. The journal would rise and shift from an effective solid contact with the bearing until it becomes practically concentric with the bearing as the speed is increased or the load is lessened. The temperature variation of viscosity, however, could not be satisfactorily dealt with as it decreases with increasing temperature and it was Andrade who suggested an exponential formula connecting the relation. The last conference on lubrication held at The Hague pointed out the various factors relating to the liquid lubricants mainly from the theoretical standpoint and it was found that in the present state of our knowledge it is difficult to apply any set formulae. The oil in the crank case of an engine under heavy duty will reach 140° C, the bearing surfaces 150° to 200° C and at the upper piston ring grooves and underside of the piston crown temperatures may exceed 250° C. The trend of automobile industry towards lower weight of engine per horse power and higher engine speed increases the difficulty of suitable lubricating oils. So the lubrication specialist is making a continued effort to understand the mechanism of the oil itself under such trying conditions. The susceptibility of the different oils to oxidation and the use of different types of inhibitors to counteract their effect has made some success. The question of film rupture is another factor concerning the contraction of the film, once it has been pierced by projections. To counteract it, one has to requisition another property, namely, that of adhesion of the lubricant to the metallic surfaces. This property is not very well understood and is designated by 'oiliness' of the liquid lubricant. The broad field of lubrication demands the attention of applied physicist in the application of the basic work on the theory of liquid state and surface phenomenon.

It is not strange, therefore, that large organisations such as Gulf Research and Development Company, and Standard Vacuum Oil Company have started organisations with applied physicists at their helm, to work out this intricate question of proper lubrication.

Secondly, the thermodynamical aspect of the conversion of heat into motive power comes into prominence here. Here one finds, different types of fuels injected into the combustion chamber, suitably ignited, finally ejected out of it into the

atmosphere. To any one, who is acquainted with the progress of this industry, it is well known how the variety of fuels so far utilised required considerable investigations to lead up to the present stage, how economic considerations are showing the need for more easily obtainable fuels.

Recent investigations regarding the design and performances of high speed engines indicate that the lines of enquiry could be fairly grouped under the following heads.

The design of the combustion chamber with its inlet and outlet valves and their proper timing mechanisms; the determination of the behaviour of the fuels during combustion; the mechanism of the expulsion of the products of combustion as noiselessly as possible.

Quite an amount of valuable work has been done regarding the proper design of the combustion chamber. The extent of our knowledge, however, about the actual process of combustion in its different stages, the intermediary products formed and the final constitution of the expelled gases are yet matters of some uncertainty. But this is of extreme importance. The thermodynamic treatment of the petrol engine does not adequately handle that portion of the cycle where combustion occurs. It takes cognisance only of the states of the system immediately before and immediately after combustion. In other words, thermodynamics pay little or no attention at present to the rate of chemical transformation during an engine explosion for want of suitable data, even though this factor determines to a large degree the rate of pressure development as well as the maximum pressure attained. Thus in the thermodynamic treatment of the engine cycle, it is frequently assumed that combustion occurs instantaneously, releasing all the energy of combustion when the piston is at the top dead centre. This is not in conformity with the actual state of affairs.

One has, therefore, to ascertain the nature of the different gases formed in the combustion chamber in the successive stages of ignition and explosion to form an accurate idea of the power developed in the process. In fact, for the study of the new cycle of an internal combustion engine or for the comparison of the different processes, such as, the influence of different heat losses, different combustion lines and different scavenging effects, the entropy diagram is of the greatest help. This has been pointed out in a recent lecture delivered by Prof. Eichelberg before the Institution of Civil Engineers, London. It is well known that the entropy of a gas can be expressed by its temperature and volume as well as by its specific heat. Now specific heat at constant volume, C_v, is du/dt and therefore one must have the energy u theoretically given as the kinetic energy of the molecules. The kinetic theory of gases shows that the rotational movement of the molecules is given by the degree of freedom and is proportional to the absolute temperature. The

quantum theory adds the energy of oscillation which is given by Einstein formula when the frequency of the atoms has been measured by spectroscopy or by Raman Effect. In deriving the entropy diagram, therefore, a knowledge of the gases developed by combustion is of some importance. Taking purely the chemical view of the problem, one should expect carbon dioxide, nitrogen and water vapour to be the gases formed under ideal conditions; but in actual practice such ideal conditions are rarely obtained, as everybody walking about the streets feels it, when he is encountered with acrid fumes emitted from the exhaust of a passing automobile. Further, any chemical method of sample analysis of the products in the various stages is beset with two main difficulties, namely, the inaccessibility of the flame and its products and the extreme rapidity of the reactions.

It will be my purpose now to show how an applied physicist has come to help the automotive engineer. Quite recently a series of systematic investigations has been conducted in the research laboratory of General Motors Company of America by Rassweiller and Withrow where purely physical methods have been adopted for the purpose. It is clear that the whole phenomenon takes place within the explosion chamber which admits fires and expells the charge thus offering facilities for the observation of the whole process in progressive stages. One has to take successive pictures of the flame production as it progresses and for this reason an experimental cylinder was designed, provided with a suitable glass top which would resist the temperature and pressure prevailing in the chamber. A suitable device has to be provided for a cinematographic film camera which could take rapid successive pictures. For this reason the camera lens has been divided into two parts. The fore-part being a stationary one which performs the first stage of the image formation of the flames and the second part consists of a number of similar lenses arranged along the periphery of a disc moving behind the fore-lens. The film in its carrier is so disposed, that whenever any of the moving lenses align with the fore-lens, an image of the flame is formed on it and this movement of the disc can be maintained in synchronism with the motion of the piston of the combustion chamber. In fact this becomes a cinematography of a rapidly moving phenomenon. The speed at which one has to operate this mechanism for an engine of 900 r.p.m. extends from 2,000 to 10,000 pictures per second. The flame pictures show that there are two regions of maximum luminosity, one in a region around the spark plug and another along the forward edge of the flame and they are of distinctly different nature.

To study the nature of these flames, the method of spectroscopy has been requisitioned and here a spectrograph is mounted in the place of the film. In fact the slit occupies the place of the film and the film, as it were, is displaced back to take the

instantaneous emission spectrum of the flame. With such an arrangement the spectrographic record shows very interesting details and is compared with the spectrum of the inner cone of a petrol torch operating in air. For the region of the flame front, one finds the familiar CH and C_2 Swan bands. The emission spectrum close to the sparking plug gives no trace of the above-mentioned two band systems. It consists of a very diffuse band system extending from 3800Å to 8500Å. They have been observed in the flame of CO and O_2 by Weston and Kondratjew and are attributed by them to carbon dioxide. In the ultra-violet region of the spectrum emitted from the flame front and after-glows, one finds OH bands. In addition to the OH bands, a group of very diffuse bands extending from 2800Å to 3700Å has been observed in flame front but not in the other region. On a careful examination of the literature on band spectra, it is found that Emeleus observed the spectra in the flame of burning ether. Quite recently Vaidya while studying the spectra of the inner cones of ethylene flames observed these two groups and attributed them to the triatomic molecule, HCO. They are entirely absent, however, in the region near about the spark plug. It may be deduced that petrol is not directly burning as a flame in the close proximity of the spark plug.

The sequence of reaction occurring in Bunsen burner flames has been carefully studied long ago (as early as 1892) by Smithels and Ingle and they found only carbon monoxide, hydrogen, carbon dioxide, water and nitrogen above the inner cone of the Bunsen burner flame. No hydro-carbons were present there. One has therefore to consider the mechanism a little more closely. Here one can state that the energy of combustion is liberated first in the flame front due to the reaction of petrol and air. Any small portion of the charge, which at the time of ignition is located near the centre of the combustion chamber, is evidently compressed by the approach of the flame and forced away from it. When the flame front reaches this portion of the charge, the sudden release of the energy of combustion quickly raises its temperature and this portion of the charge expands. As the flame moves on through the charge, the burnt gas is again compressed and it is forced back towards the spark plug so that the combustion really takes place in two stages. In calculating, therefore, the total energy of the system, one has to take into account all these considerations in the calculation of the entropy of the system.

The understanding of this process and the information secured from spectroscopic observations have recently been utilised in the design of some of the modern types of high speed engines and it has been found that their performances are in fairly close agreement with those derived from theoretical calculations.

In the study of fuel injection in the working chamber, one has to consider the action of carburetters, which by proper mixture of air and liquid fuel, produces the spray. Though Rayleigh first investigated the formation of sprays from liquid jets, it was Castleman who applied Rayleigh's theory specifically to the atomisation of liquids in an air stream under conditions similar to those occurring in carburetters. Scheubel determined the drop sizes of the sprays of alcohol—water and alcohol—petrol mixture from a carburetter jet by using spark photography and on the basis of these observations suggested a relation between air pressure, jet diameter, density of the fluid and its viscosity. The disrupted sprays were experimentally investigated by Kuehn, de Juhasz, Zahn and Schweitzer and others. From their work it is suggested that the atomisation of liquid jets may be due to the turbulence of the liquid and a critical velocity is required to produce the turbulence.

There has been a large number of theoretical and experimental investigations to understand the proper mechanism of jet formation in different types of fuels and still there are factors awaiting solution.

Now, about the exhaust. One gets some idea of the complicated motions in the exhaust of an engine by a close observation of the swirling motion of smoke issuing from a chimney or the more complicated motion of steam issuing from the funnel of a locomotive or still more complicated motion of the smoke cloud issuing from a big gun after firing of the projectile. The usual formula is based upon the assumption of steady state in the chamber, so that the distribution of energy in the chamber may be ignored and the kinetic energy of the issuing jet equated to the work done in maintaining constant pressure in the chamber. Exhaust of an engine is a transient phenomenon. Hence a great deal of justification is required in applying to it a formula, relating to a steady state, in which it is assumed that the energy in any particular unit of the gas, remains in the same unit throughout its passage through the chamber and the exit pipe and that no unit gains energy from or loses it to neighbouring units. The present state of the theory is in a rather unsatisfactory state. Quite recently a number of experimental studies are being conducted to secure materials for the proper development of the theoretical aspect.

Aeronautical Industry.

Air transportation is the youngest of any of the industries so far discussed. In its commercial aspect it is truly an 'infant industry'. Not only the designers but also the executives are on the average very considerably younger than the men occupying analogous positions in most other industrial fields. The industry has grown up with an unusual absence of tradition

and experience. This is indicative of the fact that all the developments have been based, to a remarkable extent, on the results of research and theoretical calculations. An important feature of aeronautics lies in the extreme narrowness of the margin between success and failure and in the terribly serious consequences which may result in failure. This has placed a tremendous premium on exactitude and has greatly stimulated activity in research of all kinds. All the problems of aeronautics are essentially physical in nature and it is therefore not strange that it has furnished an unusual field for the intensive use of applied physics. I shall merely mention a few of the various branches of applied physics which have been applied to aeronautical problems and then shall discuss in a little more detail the most fundamental aspect of them.

For any fuel burning power plants, thermodynamics plays an essential part. The difficult problems of heat conduction have to be solved in aeronautics, because aircraft engines demand high pressures for large power output, consistent with low weight and economic fuel consumption. One has to be acquainted with the physics of the air to reckon the meteorological factors on which are based the different problems of flight. Without this aid, air transport would be almost impossible, since weather troubles would make air services so unreliable as to eliminate most of its economic usefulness. Electricity and magnetism have largely been used in connection with aircraft instruments and radio, two of the elements of vital importance for satisfactory air travel. For noise reduction acoustics have recently been requisitioned. Mechanics in the field of aeronautics is of basic importance. It is well known that many of the basic laws of mechanics were discovered as a result of problems which arose in the attempt to serve specific engineering needs. The classical laws of mechanics formulated in the middle of the eighteenth century had an elegance and generality which attracted mathematicians and theoretical physicists and were far from the actual conditions encountered in practical working. In hydrodynamics, for example, for obtaining exact solutions of the equations, viscosity had been neglected. Frictionless fluids form the basis on which classical hydrodynamics is developed. In engineering hydraulics as developed by practical workers, one finds countless numerical coefficients entirely divorced from the mathematical theory of hydrodynamics and it was extremely difficult to secure generalised relations to form a rational scheme.

It was Felix Klein who first realised this defect in the outlook of engineers and began to build up a school of applied mathematics and applied physics which developed a new interest and new point of view so as to bring engineering and science closer together. Among the group of people associated with him Prandtl, Von Karman and Timoshenko are best known as

pioneers in this line. Their main effort had been in obtaining approximate solutions of more specialised equations in which all the essential physical elements of a particular problem are included.

The theory of the aircraft structures is concerned with the transmission of the air forces from the surfaces where they arise and to the useful load which they carry. The aeroplane requires a smooth strong external surface for the air pressures to act on. The external surface has to perform two functions simultaneously, namely, carrying the external pressures and serving as an integral portion of the major structure. In the most modern type of aircraft, the older types of design having a sort of skeleton structure with a covering fabric forming the external surface, have been abandoned. They have been replaced by the so-called 'monocoque' type of design in which the surface is made of thin metal and carries a considerable fraction of the major structural loads. The structural members usually have lengths which are very large compared to their transverse dimensions.

The use of the 'monocoque' construction and the great slenderness of the structural members result in tendencies towards instability or local buckling. For long compression members like struts, beam flanges, etc., the problem has been attacked in two manners. Firstly, by designing the structures so that such members have lateral support at frequent intervals. The ratio of length to transverse direction is kept fairly small between supports so that tendency for buckling is reduced. Secondly, carefully worked out cross-sectional shapes are determined so as to distribute a given amount of inertia and increased resistance to buckling. It was easily noticed that in order to prevent buckling of the struts, the thickness would have to be so great and so many stiffening elements would be necessary that the weight would be prohibitive. Wagner, after a careful study, took the bold step of conceiving structures which were allowed and even designed to develop wavy shapes under load. The structure would not buckle in normal flight but goes into a wave state during the brief instant when the loads are higher than normal. The theoretical design formula worked out by Wagner forms the basis of all modern constructions and serves their purpose well.

Turning now to the field of aerodynamics one finds that the earliest scientific analysis of this question was the work of Newton who developed a theoretical formula for the lift of a flat plate. This formula predicted that the lift should be proportional to the square of the angular inclination of the plate to the wind. From this formula, one finds that in order to obtain reasonable lifts, enormous amount of power would be required to drive the plate through air fast enough to retain this high angle of inclination. It was only near the beginning

of the present century that actual machines had been built which were capable of flying and on careful examination by the theoretical physicists, it was found that the lift of a plate was proportional to the angle of inclination rather than to the square of the angle.

The relation between the lift and the wind inclination, as well as resistance to forward motion or the drag, depend largely on the wing span, i.e., the lateral expansion of the supporting wings. Here were encountered great difficulties in design till 1911 when Prandtl worked out a purely theoretical analysis of the problem, which led to a very simple formula connecting effect of span on drag as well as the relation between the lift and wing inclination. The pressure drag which is the resultant of all normal pressures acting on the surfaces of a body moving through a fluid has been discussed by Helmholtz, Kirchoff and Rayleigh but owing to the absence of suitable data, these theoretical studies did not find successful application. In 1911 Von Karman showed that by proper 'stream lining' this pressure drag could be completely eliminated. There was yet another factor, namely, the friction encountered by the moving body in motion. This has been the subject of study by Prandtl who showed that the influence of friction was confined to a thin 'boundary layer' close to the surface of a body moving through the atmosphere.

The problem of 'stability', i.e. the disturbance effect produced by gust of wind or movements of controls on the normal flying condition, was not very clearly understood. Bryan undertook the study of this problem and arrived at a solution. Though it is highly involved, requiring extensive mathematical technique, yet it forms a basis of calculation and several approximations have now been adopted which have rendered the solution of the stability problem much more easy than before.

The question of 'turbulence' attracted some of the best brains in the world for the last fifty years and yet it remains in a state of uncertainty. Osborne Reynolds studied the subject as early as 1883 and arrived at the relation between the different types of fluid motions and their dependence on speed. The distinction between 'laminar motion' and 'turbulent flow' of a fluid and their dependence on the 'critical speed' were worked out by him. The so-called Reynolds number and a critical Reynolds number at which transition occurs from the 'laminar' to the 'turbulent' state exist for almost every type of fluid motion. It appears that in practically all cases of technical importance in aerodynamics the range of Reynolds numbers encountered lies far above the critical one, so that a knowledge of the nature of turbulent flow is of extreme practical importance.

Extensive experimental investigations to ascertain the nature of turbulent flow have been conducted. The hot wire anemo-

meter has been widely used for the purpose. Oscillograms of these records have disclosed their complicated nature and still demand careful analysis. The statistical treatment of the problem regarding the mechanism of turbulence by G. I. Taylor may prove to be a very efficient tool which will finally build up a consistent theory.

The recent researches on the aerodynamics of aircraft have attracted considerable attention of eminent applied physicists. Prof. Melville Jones of the Cambridge University has been applying with great success the Pitot-travers method for drag measurements. The measurement of the profile drag on an aeroplane wing by Relf in the compressed air tunnel at the National Physical Laboratory is of great value. In fact the experimental observations now reach up to Reynolds number value of about 24 millions, a value appropriate to the fast modern aircraft.

The co-operation between the actual observations and experimental work of the aerodynamic laboratories is now proceeding very closely. The observation of squadron leaders in actual flight are now communicated to the theoretical physicists and to those engaged in wind tunnel experiments so that effective changes in the shape, structure, and surface of the aircraft are being continually modified consistent with the above-mentioned background. There yet remains ample scope for research on numerous problems of stability and control. Oscillation problems have been treated generally on the basis that forces at issue are linear functions of velocity and displacements, whereas such factors as controlled and mechanical friction introduce non-linear relationship which has to be taken into account for safe high speed flying.

The whole aspect of aerodynamics leading to the design and construction of aeroplanes is now engaging the attention of an earnest band of workers toiling ceaselessly to obtain practical data by the application of physical principles.

Already the theme has become fairly large and it is not my intention to multiply instances so that one may realise the important rôle of applied physics in industries. I am afraid, already I have passed the limit of your patience with which you have so kindly favoured me till now. In spite of this, I cannot but draw your attention to the part which applied physics is now playing in agriculture, land survey, meteorology and biological sciences. In the different industries such as, the textile, paper, glass, rubber, abrasives and in various other industries, large and small, the unseen influences of physical methods and appliances are ceaselessly working for better production and economic development. Illumination of our highways, schools, workshops, public places of amusement indicate the useful character of the application of physics. I cannot but mention the different aspects of vibrations and

forced oscillations in its different effects, modifying our social well-being. In this connection it will not be out of place to mention a very striking example. I would like to refer to you the case of the terrible railway disaster at Bihta in 1937. It is well known that the Government of India appointed a special committee, known as the 'Pacific Locomotive Committee', to investigate the cause and suggest remedies for the future non-recurrence of such accidents. I hope all of you are aware that to study the vibrations and oscillations produced in the tracks and engines, a special observation car was fitted up by the Chief Electrical Engineer of G. I. P. Railway, Mr. Mulleneux, and the vibration recording devices designed by the French physicist and railroad engineer Hallade were requisitioned. After the systematic study over several hundred miles of tracks of the behaviour of this special pacific locomotive XB and XA classes of engine, the Committee recommended certain modifications and additions to the engine for its safe running. It was further suggested by the Committee that an enlarged organisation for research and standards should be taken up by the Railway Board to determine the actual vibration and oscillation conditions in tracks and locomotives all over India to ensure their safe running.

Last but not the least is the contribution of applied physics to industries in the different 'Measuring Instruments'. Thus in our land survey from the simple measuring chain to the modern aerial photographs for the contour survey of inaccessible region are but examples of its utility. For the control of every industrial process, the measurement of pressure, force, energy, frequency and numerous other mechanisms are finding place. For interchangeable part of machinery and equipment, precision gauges, jigs, ruling engines, projection devices are becoming more and more evident. The measurement of temperature is an important factor in our daily life and the use of temperature measuring devices such as the thermometers, and the different classes of recording and non-recording pyrometers are becoming absolutely essential in the industry. Regarding electrical instruments, apart from voltmeters, ammeters, energy-meters, frequency-meters and power-factor meters, which are practically developments in one form or other of the galvanometers used in laboratories, one finds a large variety of instruments with modifications suitable for the purpose to which they are to be applied. The steady growth of radio and broadcasting and that of the aircraft created a demand for numerous types of measuring instruments which are primarily born in laboratory but put to industrial use in its multifarious forms. Finally, I would say that the contribution of applied physics to other sciences and to industries is becoming increasingly felt and it is expected that in the near future as time progresses, there would be greater and greater demand for applied physicists in industry.

SECTION OF CHEMISTRY

President :—MATA PRASAD, D.Sc., F.I.C., F.N.I.

Presidential Address

(Delivered on Jan. 3, 1941)

PHYSICO-CHEMICAL STUDIES OF GELS

In the great science of the structure of matter the science of colloids represents the domain which lies above the molecular and below the macroscopic dimensions. In this domain there lie a number of systems which form the basis of essential material processes affecting life as a whole. Considerable advance has taken place in our knowledge about these systems during recent years and these have opened up the possibilities of wide and far-reaching applications of this branch of chemistry in both theoretical and practical sciences.

In this address I propose to deal with one of the numerous systems of colloids, namely, the 'gels' in which I have been interested for the last fifteen years. The name 'gel' was first introduced by Thomas Graham, the founder of colloidal chemistry, to designate the precipitate formed on the addition of electrolytes to colloidal solutions or what are commonly known as sols. This term has now acquired quite a different meaning. According to Freundlich [1] colloidally disperse structures consisting of a solid and a liquid phase or of two liquid phases, and having shape and cohesion, that is, elastic properties, should be called 'gels'. However, some authors have preferred to use the term 'jelley' for elastic gels in which the amount of the enclosed liquid is relatively enormous. McBain [2] holds the view that those jellies which differ from sols in elastic properties only should be considered as gels, but the number of such systems which are so alike in the sol and gel states is very small. Further, McBain's definition excludes a number of systems which have been described as gels by several writers and are of great scientific and industrial importance. Thus it seems that it is not quite easy to put forward a definition so comprehensive as to include all the known gels within its scope. The definition given by Freundlich has been adopted by the writer throughout the present discourse.

The earliest known gels were those of gelatin and silicic acid. The former were obtained in transparent and elastic state and were heat reversible while the latter were known to

be opaque and were considered to be inelastic. These characteristics have given rise to classification of gels into various divisions such as transparent and opaque, elastic and rigid, and heat reversible and heat irreversible. Although many of these divisions have gone out of vogue, the one between organic and inorganic, determined by the nature of the substance in the gel condition, is still retained. If we accept this classification there is need for introducing another division to include gels prepared from inorganic salts of organic acids. These could be called inorgano-organic or organo-inorganic gels, not only on account of the nature of the substance in the gel state, but also from the consideration that some of the characteristics of this type of gels are allied to those of truly organic gels while other properties are related to the truly inorganic ones.

Organic gels

Earliest known gels belonging to this class are those of gelatin and agar-agar. These are fairly complex organic substances derived from animal and vegetable matter, respectively, and are made up of an unknown number of unisolated chemical entities. Gels of pectin derived from several fruits are also quite well known. Recently, gels of cellulose acetate and of geranin and viscose, which are substances of no less complexity, have been prepared by Mardles [3] and Liepatoff [4]. Nevertheless, literature abounds in the description of gels of several definite organic substances, some of which exist in crystalline form. The gels of these substances have been obtained either in aqueous medium or in some suitable organic solvent. Glycyrrhizic acid [5], camphoryl phenyl thiosemicarbazide [6], azomethine [7], dibenzoic acetal of sorbitol [8], benzopyrone derivatives [9], benzopurpurin 4B, and crysophenin B [10] can be cited as a few instances.

The usual procedure adopted for the preparation of these gels consists in preparing a solution of the gelling substance in a solvent at a high temperature and then allowing this solution to cool either slowly or rapidly. Instances are, however, known which show that the procedure described above is not applicable to the formation of all organic gels. Thus, for example, solutions of nitro-cellulose [11] in a mixture of amyl acetate and benzine, of nitro-cotton [12] in alcohol and of methyl cellulose [13] in water, have been found to gelatinise on heating. Further, it has been found that neither heating nor cooling is necessary for the formation of gels of dibenzoyl cystine [14]. These are prepared by merely dissolving the crystals of the substance in alcohol and pouring the solution into water.

Inorgano-organic gels

Several gels belonging to this class are known and while some of them have been prepared in organic solvents, others

are easily obtained in aqueous medium. Gels of barium malonate [15] form a good example of the former type. They are prepared by mixing solutions of suitable concentrations of barium hydroxide and malonic acid in methyl alcohol in the presence of certain amount of glycerine. Gels of lithium urate [16] and those of soaps are best instances of the latter type. Considerable amount of work has been done by McBain and co-workers [2] on aqueous solutions of alkali salts of higher fatty acids. To these they have given the special name of colloidal electrolytes. They have shown that an aqueous solution of sodium oleate can be brought in any of the three typical colloidal states, namely, clear oily liquid sol, white opaque solid curd, and clear transparent elastic gel. Gels containing a low amount of sodium oleate are obtained by very slow warming of the curd while those of high soap content are prepared by cooling the sol.

Soap gels have also been prepared in non-aqueous media. Fischer [17] obtained a non-syneretic gel of sodium arachidate in methyl alcohol and Miss Laing and McBain [18] prepared gels of potassium and sodium soaps in alcohol-water mixtures. Recently, it has been found at the Royal Institute of Science [19] that sodium and potassium salts of oleic, stearic and palmitic acids dissolve easily in pinene at about 140° and the resulting solutions set to transparent colourless gels when cooled to room temperature. All these gels are heat reversible and some of them show the phenomenon of syneresis.

Inorganic gels

The earliest known gel belonging to this class is that of silicic acid. This has been prepared by several workers usually by the action of acids, organic and inorganic, upon sodium silicate. Bhatnagar and Mathur [20] showed that these gels can be very conveniently obtained by mixing suitable solutions of sodium silicate and ammonium acetate. In recent years, a large number of gels of inorganic substances have been prepared and some of them have been obtained in as transparent a state as the organic gels. An account of the preparation of gels of hydroxides, phosphates, arsenates, molybdates, etc., of several metals is given by Satya Prakash [21] who has himself prepared several of these gels for the first time. The methods employed for the preparation of these gels can be classified as follows:—

(1) By mixing the constituents of the gel-forming mixture. In some cases, this results in the formation of a clear solution which goes over to the colloidal state, and in other cases, a precipitate is formed and it disappears on slight or vigorous shaking.

(2) By the addition of electrolytes to a fairly concentrated and suitably dialyzed sol of the gelling substance, or by the prolonged dialysis of such a sol.

(3) By changing the solvent or by the dilution of a true solution of the gelling substance which is sparingly soluble in the changed or the diluted solvent.

The hydrogen-ion concentration of mixtures giving rise to inorganic gels exerts a profound influence on the nature, the appearance and the characteristics of the gel. It has been found in the case of silicic acid that using the same solution of sodium silicate and different solutions of acidic ammonium acetate, two types of gels are obtained, one in the alkaline medium and the other in the acidic one [22]. Not only is the mode of formation of these two gels different, but they also differ from each other in appearance, the one formed from acidic medium being more or less transparent. The results of this investigation have led to the preparation [23] in a transparent state, of a number of inorganic gels which had been obtained previously only in an opaque or translucent condition. For this purpose acids instead of alkali salts of the acids corresponding to the acidic radicals of the gel-forming substance have been employed, wherever possible, and, if necessary, suitable amounts of hydrochloric acid have been added to the gel-forming mixtures.

Sol-gel transformation

The sol-gel transformation is irreversible in some cases, while in other cases, a gel can be converted into a sol and back to gel any number of times at will. The reversible sol-gel transformation in the case of organic and some inorgano-organic gels is brought about by heating or cooling and is called non-isothermal reversible transformation.

Recently, Szegvari and Miss Schalek [24] discovered that gels of iron hydroxide show the phenomenon of isothermal reversible sol-gel transformation which has been named thixotropy. A thixotropic gel goes over to the sol state by mere shaking or stirring or by some mechanical action or under the influence of ultrasonic waves and sets again to the gel state when left to itself. This process can be repeated at will. Gels of aluminium hydroxide, vanadium pentoxide, thorium molybdate, thorium arsenate, are some of the many instances of thixotropic gels. The thixotropic change, in some cases, is accompanied by reversible changes of colour; for example, the iron oxide sol to which sodium chloride is added, appears golden brown and clear while the gel looks yellow and turbid [25].

It has been observed by Prakash [26] that if gels of ferric phosphate and arsenate, thorium molybdate and phosphate and aluminium and zirconium hydroxide are frozen in liquid air and brought to room temperature, a sol is again formed which sets to a gel after a time. This process of reversible sol-gel transformation can be repeated at will. He has named this phenomenon as cryotropy.

A new kind of reversible sol-gel transformation has been found by my collaborators and myself [23, 27] with gels of thorium phosphate and arsenate prepared from thorium nitrate and phosphoric and arsenic acids, respectively. They go over first to the sol state and then into solution when desiccated over calcium chloride and reset to a gel when the necessary amount of water is added to the solution. A similar behaviour was observed by Freundlich with iron oxide sol which sets to a thixotropic gel on the addition of alcohol and the gel is reconverted to a sol when desiccated over water [24].

Microscopic investigations

The scientific mind is not content with the mere preparation of a substance and observing the transformation it undergoes; it strives to probe deeper and search for its constitution. It is, therefore, not surprising to find that even in the early days of the development of this subject the attention of some investigators was directed to various enquiries regarding the internal structure of gels, such as, the size and shape of the ultimate particles of which a gel is composed, the mechanism by which a system containing only a small amount of the solid matter and a large volume of the liquid phase gives rise to a solid-looking substance, the manner in which the liquid phase is held in the gel system and several other aspects.

To answer these questions attempts were made in the beginning to observe the structure by means of a microscope and an ultra-microscope. The microscopic examination by Hardy [28] of a solution of gelatin undergoing gelation revealed that when the solution is cooled below 20°, a cloudiness first appears, due to the formation of fluid droplets which, on further cooling, solidify and adhere to one another. Zsigmondy [29] examined ultra-microscopically the dry gels of silicic acid as well as those filled with liquid, and found that they were mostly optically empty. However, on drying the gel, he could obtain some evidence of the existence of submicrons. Bachmann [30] also followed the gelation of silicic acid, gelatin and agar sol through an ultra-microscope. In a one per cent solution of gelatin he observed that some time after the solution is made, there appears a crowd of submicrons in lively movement which ceases when the gel is set.

The above are the only few instances in which results of any significance have been obtained. In the case of other gels the microscopic and ultra-microscopic examinations have revealed no structure but have only indicated that the particles in gels are too fine to be seen by these instruments and hence their diameters are of the same order of magnitude as the wave-length of light. This is due to the fact that the application of these instruments to the study of gels has several limitations. For

example, if the particles are too small to be optically resolved or too numerous or if the difference between the refractive indices of the particles and the dispersion medium is inappreciable, only uniform illumination is seen instead of diffraction images due to the particles.

Recently, the newly discovered electron microscope has been employed for the determination of the shape of particles in the sol condition. Beischer and Krause [31] have found that the particles in a gold sol are cubical and those in an iron sol are thread-like. No application of this instrument for determining the shape of particles of substances in the gel state has so far been reported.

Properties of gels

As no results of definite character regarding the gel structure could be obtained by direct examination, the workers in this field took to a systematic study of the various properties of gels and the changes which they undergo during the process of gelation or sol-gel transformation. It is no exaggeration to say that the great bulk of information of immense significance in postulating theories of structure of gels has been indirectly derived from such a study. An account, which is by no means complete, of the important results obtained from some of these investigations is given in the following pages.

(A) Time of setting

The time of setting is the main property which characterizes a gel. Various workers have employed different criteria for the setting of a gel. The general consensus of opinion is inclined to the view that the attainment of a certain viscosity by the gel-forming mixture should be employed as the criterion for the setting of a gel. But such a criterion gives only a relative and not an absolute value of the time of setting. Further, it implies that all changes involved in the process of gelation are completed during this period. This is not entirely correct.

Methods which have been employed so far for the determination of the time of setting are as follows:—

(1) Fleming's method [32] which consists in determining the time which a gel-forming mixture takes to reach a consistency which will prevent it from flowing out of its container.

(2) Fells and Firth's method [33] depends upon the criterion that the pressure required to blow a bubble of air or of mercury or of chloroform through a gel-forming mixture reaches a maximum value at the time of setting.

(3) Hurd and Letteron's method [34] consists in placing a rod in the gel-forming mixture in a certain position by the help of a suitable support and the time which the mixture takes to reach a state when the rod can remain in this position without the support, is the time of setting.

(4) Prasad and Hattiangadi's method [22] involves the measurement in the changes in the intensity of light from a constant source transmitted through the gel-forming mixture. The gel is considered to have set when these changes reach a constant value.

The measurement of the time of setting of the same gel-forming mixture by the above-mentioned methods has given values which are widely different from each other [35], and hence has experimentally confirmed the view concerning the usefulness of these methods for comparative studies only.

Most of the work on the time of setting has been done on inorganic gels, mainly at Allahabad, at the Royal Institute of Science, Bombay, and by Hurd and co-workers. The latter workers are to be credited for giving the time of setting the importance which it deserves. They [36] assume that the setting of a gel is a process which follows the laws of ordinary chemical reactions, so far as its velocity is concerned, and that for a given run, the time of setting measures the time when a certain fixed proportion of silica, in whatever form, has reacted. On the basis of these assumptions they have extended the application of Arrhenius's equation to the setting of silicic acid gels and, in agreement with the requirements of this equation, have found that the curves obtained on plotting the logarithm of the time of setting against the reciprocal of absolute temperature are straight lines. The heat of activation of silicic acid gel calculated from this data has been found to be independent of the nature of the acid used for the preparation of the gel. These investigations thus point out the importance of temperature control in the determination of the time of setting of gels.

The assumptions mentioned above have been found to apply equally well to other inorganic gels studied by Prasad and co-workers [23]. The time of setting of the gels has been found to decrease with rise of temperature but the heats of activation have been found to alter with a change in the concentrations of the constituents of the gel-forming mixtures. In some cases, particularly in the case of gels of thorium arsenate, the time of setting has been found to increase with temperature and the heat of activation is negative.

Similar measurements in the case of organic gels are not possible since they would not set at temperatures at which the solutions are made. Hence a considerable time would be lost and a part of the setting process would be completed before these solutions are brought to setting temperatures. In such cases we have suggested [37] that the time required by a gel-forming solution to set to the gel state when it is allowed to cool from a certain high temperature to a known lower temperature, may be taken as the time of setting of the gel at the lower temperature. Probably the same procedure has been followed by Olsen [39] who studied the time of setting of gelatin gels at

various temperatures. A study of the cooling curves of solutions of sodium oleate in pinene [38] has revealed that the time taken by these solutions to cool down to the temperature of the bath (lower temperature) is a considerable fraction of the time of setting in accordance with the definition given above. Sufficient data are not yet available to draw conclusive inferences regarding the applicability of Arrhenius's equation to all organic gels. However, in several cases [37] straight lines have been obtained on plotting the logarithm of the time of setting against the reciprocal of the absolute temperature. These straight lines show that the heat of activation of these gels is negative and their time of setting increases as the temperature of setting is raised.

Thixotropic gels are characterized by a second time of setting which is called 'thixotropic time of set'. This is shorter than the proper time of setting of gels and is the time taken by thixotropic gels to set after they have been liquefied by some mechanical action. It is remarkable that this time has practically constant value, that is, it can be repeated as often as one likes, and is independent of the agency employed for bringing the gel into the sol state. This gives only an arbitrary way of defining thixotropy.

It has been observed that the time of setting of an aged thixotropic vanadium pentoxide sol is reduced to one-fourth if the tube containing the sol is given a rotatory motion backwards and forwards by moving it between the palms of the hands. This phenomenon has been called 'Rheopexy' by Freundlich and Juliusburger [40].

The time of setting of gels is considerably altered by the changes in the concentration of the gel-forming substance or of the constituents of the gel-forming mixtures. In the former case the setting time decreases with an increase in the concentration but in the latter, it usually increases with an increase in the concentration of the constituent containing the metal ion of the gel-forming substance and decreases with an increase in the concentration of the other constituent. In the case of silicic acid gels prepared according to Bhatnagar and Mathur's method it has been found that with an increase in the concentration of acidic ammonium acetate the time of setting first decreases, reaches a minimum value, then increases and reaches a maximum value and again decreases [22]. Similar observations have been made in the case of some other gels as well [23].

The time of setting of a gel has been found to depend specifically upon the hydrogen-ion concentration of the gel-forming mixture. Freundlich and Sollner [41] have found that the time of setting of an iron hydroxide sol increases from 82 seconds to 9,000 seconds when the pH is changed from 3·86 to 3·11. The effect of hydrogen-ion concentration has been exhaustively studied by Hurd and co-workers [42] in the case of the silicic acid gels. They find that a linear relationship holds

between the time of setting and the hydrogen-ion concentration. Hurd and Paton[43] have, in a recent publication, confirmed in a remarkable manner the specificity of the effect of *p*H upon the time of setting. On adding the same amount of acetic acid to the same silicic acid gel-forming mixture at different intervals from the commencement of the formation of the gel, they have shown that the setting of the gel proceeds at the same rate as without the addition of the acid for the time before the acid is added and subsequently at the rate followed in the presence of the acid added at the commencement of the setting. It has been recently found that an approximately linear relation also exists between the time of setting and the hydroxyl-ion concentration of alkaline silicic acid gel-forming mixtures.

Results of similar investigations on the time of setting of thorium arsenate and thorium phosphate gels by Desai and Miss Nathan[44] at the Royal Institute of Science, have shown no linear relationship between the time of setting, determined by Hurd and Letteron's method, and the excess of hydrochloric acid added to the gel-forming mixtures. They find that with an increase in the amount of the acid in the gel-forming mixtures, the time of setting first decreases and then increases.

The time of setting of gels is very sensitive to the addition of small amounts of electrolytes and non-electrolytes. The effect of these agents was first systematically studied by Prasad and Hattiangadi[45]. They showed that the time of setting of alkaline silicic acid gels decreases while that of acidic ones increases on the addition of various alcohols to the gel-forming mixtures. This work has been extended by Hurd and Carver[46] and Munro and co-workers[47] who have examined the effect of several polyhydric alcohols, sugars, acetone and aldehyde, on the time of setting of silicic acid gels, and by Prasad and Desai[48] to the case of several transparent inorganic gels prepared by them.

Thixotropic time of setting is also influenced by changes in (i) the concentrations of the coagulating agents or of the constituents of the gel-forming mixtures, and (ii) the hydrogen-ion concentration of the gel-forming system, and (iii) by the addition of non-electrolytes. A change of temperature also alters the thixotropic time of setting and the changes are governed by Arrhenius's equation[49].

(B) Elasticity

The next property which is characteristic of the gel state alone is elasticity The importance of this property was recognized even in the early days but its significance in elucidating the structure of gels has been understood only recently. Most of the work on the measurement of modulus of elasticity has been conducted on organic gels, particularly on the gels of gelatin which have been found to follow Hooke's law[50] and the modulus has been shown to vary as the square of the

concentration [51]. Recent measurements by Hatschek [52] with a highly improved apparatus have shown that the gels containing 8–12 % of gelatin have a well-defined modulus up to a load corresponding to 45 g. per sq.cm., and this value is repeatable within about 3 per cent.

The value of the modulus has been found to change with a change in the quality of the gelatin and the hydrogen-ion concentration of the gel-forming system. Freundlich and Neukirchu [53] found a minimum in the neighbourhood of the isoelectric *p*H while Kunitz [54] found that acids and alkali strongly reduce the elastic modulus of the swelling gels. The modulus is also altered by the addition of substances like alcohol, sugars, glycerol and inorganic salts, to the gelatin gels. Poole [55] has shown recently that the extension of a rod of gelatin gel increases with time and that the elasticity of the gel also varies with temperature. The strain produced in the gel causes double refraction which is roughly proportional to the concentration.

Some observations have been reported on the measurement of elasticity of gels of cellulose acetate by Mardles in 1923. The systematic work on these gels has been carried out by Poole [56] who finds that the elasticity of these gels also varies with time and temperature and approximately as the square of the concentration.

No systematic work of this nature has been done on silicic acid gels which have been considered as inelastic. The measurement of the elasticity of compressed silicic acid gels by the writer [57] has revealed that they obey Hooke's law up to the breaking point but the elastic limit is low. The elasticity of several other inorganic gels has been measured by Yajnik and collaborators [58].

Gels of silicic acid emit a peculiar note when they are suitably made to vibrate. The sonorous property of these gels has been noticed by several workers and has been studied systematically by Holmes, Kaufmann and Nicholas [59] with gels contained in tubes. The writer measured the velocity of sound in the compressed gels and found that the elasticity calculated from the relation applicable to isotropic solids is in fair agreement with the experimental value [57].

(C) Viscosity

Several references have been made to the effect that elasticity is related to viscosity, but no definite mathematical expression of general application correlating the two constants has so far been put forward. Notwithstanding this view, the importance of viscosity as a characteristic property of a colloidal system was recognized by Graham who was the first to suggest that the viscometer should be employed as colloidoscope. Wolfgang Ostwald while inaugurating a General Discussion on Colloids and their Viscosity under the auspices of the Faraday Society

stated in his introductory address, 'The determination of viscosity is a prominent methodic principle in investigating the properties of the colloidal systems which are usually described as changes of state'. Further, he mentioned, 'Among all the properties, viscosity occupies a central position, firstly because it shows the largest possible variation with small changes in the colloidal condition' and secondly because it 'permits quantitative measurements . . . by a method not too complicated'.

Usually, the viscosity of a system undergoing gel-formation has been measured by the flow of the gel-forming mixture through a capillary tube (Ostwald's and Scarpa's methods). Mardles [60] has systematically studied the effect of the diameter of the capillary tube on the viscosity-time curves obtained during the formation of cellulose acetate gels in benzyl alcohol and has also employed rotating cylinder and falling sphere viscometers for these measurements. He finds distinct differences in several measurements and concludes, 'with gelating sols the viscosity values have lost their usual significance and are empirical but they are valuable in that they indicate the progress of gelation'.

Earlier measurements of viscosity during gel-formation were done mostly on gelatin solutions and some empirical relations between changes in viscosity with time were found out. The results obtained during the gelation of solutions of cellulose acetate in benzyl alcohol (Mardles) could be expressed in the form of an exponential equation which shows that the rate of increase of viscosity with time is proportional to the increase of viscosity at that time. This relation has also been found to hold for the viscosity changes with time in silicic acid gel-forming mixtures [61] and solutions of sodium oleate in pinene [62] but is not obeyed in the case of other inorganic gels.

Prakash and Dhar [63] have measured the viscosities of several gels during setting and have shown that their results indicate three distinct stages during the process of the formation of gels. The viscosity measurements carried out at the Royal Institute of Science [64], have failed to show these stages and hence it has been suggested that if they exist at all, they run simultaneously and lend to the whole process of gelation an aspect of continuity. It has been noted in all the studies that the viscosity increases only slowly in the earlier stages but after some time the rate of increase of viscosity becomes very rapid.

Changes in viscosity of inorganic gel-forming mixtures during setting are considerably modified by changes in the concentrations of the constituents of the gel-forming mixtures, the addition of extra amounts of electrolytes and non-electrolytes, and temperature. It has generally been found that an increase in the concentration of the metallic ion of the inorganic gel-forming substance decreases the rate of increase of viscosity while an increase in the concentration of the other ion increases

it. It has been suggested that in the former case there is an increase in the density of charge on the particles of the gel-forming substance and hence an increase in its degree of dispersity and a decrease in the degree of hydration [65].

The addition of alcohols has been generally found to retard the rate of increase of viscosity with time in acidic silicic acid gel-forming mixtures and the reverse happens in the alkaline ones [66]. Similar effects have been observed with gels of thorium phosphate, thorium arsenate and stannic phosphate. The effect of the addition of increasing amounts of hydrochloric acid has been studied by Miss Nathan who finds that the rate of change of viscosity with time increases up to a certain amount only; further additions effect a decrease in the viscosity changes.

Increase of temperature increases the rate of increase of viscosity with time for all the inorganic gel-forming mixtures studied so far, thorium arsenate being the only exception to the above rule. The reverse effect takes place on the viscosity changes with time in the case of the organic gels, on rise of temperature.

The study of the change of 'viscous behaviour' has also been suggested by Freundlich as the best method of attacking the problem of thixotropy in a quantitative manner. Viscosity measurements during the setting of thixotropic gels of thorium molybdate [67] and of stannic hydroxide by capillary viscometer have yielded viscosity-time curves which are discontinuous or zonal as named by Joshi and co-workers [68] who were the first to obtain zonal viscosity-time curves during the studies of the coagulation of several colloidal solutions by electrolytes carried out at the laboratories of the Hindu University. The nature of zones in these curves has been found to change with a variation in (i) the concentrations of the constituents of the gel-forming mixtures, (ii) the hydrogen-ion concentration, and (iii) temperature, and (iv) by the addition of extra amounts of electrolytes and non-electrolytes. Such curves have not been obtained in the case of thorium arsenate gels [64] which are also known to be thixotropic. Hence it has been suggested by us that the zonal nature of the viscosity-time curves may be taken as a characteristic of highly thixotropic gels only.

Goodeve and Whitefield [69] have shown that for quantitative work it is necessary to determine the resistance to flow, that is, the rate of increase of viscosity under constant shear in a fairly short time—a condition which is not reached in the usual methods employed for the measurement of viscosity. According to them under conditions of steady shear there is an equilibrium between the rate of increase of the concentration of the micelles and the rate of their breakdown, and the apparent viscosity η of the system is given by

$$\eta = \eta_0 + \frac{\theta}{S}$$

where η_0 is the residual viscosity, S the shear, and θ the *coefficient of thixotropy* which may be stated as the rate of growth of structural viscosity with time divided by the probability of the viscosity being broken down in unit time by unit shear. They have devised an apparatus for the measurement of the apparent viscosity of a thixotropic system at different rates of shear and have shown that the curves obtained on plotting the observed values of viscosity against the reciprocal of shear are straight lines at high rates of shear and are independent of the rate of shear. The limiting slopes of these lines are the coefficients of thixotropy. Measurements made on thixotropic suspensions have yielded results which are in conformity with the theory but no such work has so far been carried out on thixotropic gels considered in this discourse.

(D) Optical Properties

The study of the optical properties of gels has a great advantage over the viscosity as in this case the observation can be made without disturbing the internal equilibrium of the system. Optical properties which have been studied during the process of gel-formation include mainly (1) the scattering of light and its polarization, (2) refractive index, (3) extinction coefficient, (4) turbidity, transparency or opacity.

The method of scattering of light was first developed by Lord Rayleigh [70] with a view to obtain information regarding the size and shape of colloidal particles and the colour changes which accompany the coagulation of sols by electrolytes. Arisz [71] extended this method to the study of the transformation of the glycerol sols of gelatin to the gel state and found that the rate of change of the intensity of scattered light increases rapidly with temperature during gelation. Kraemer and Dexter [72] also found an abrupt rise in the intensity of the light scattered by gelatin solutions at temperatures below 30° within a very narrow range of *p*H near the isoelectric point. Duclaux and Hirata [73] have, however, pointed out that this increase is not due to an increase in the volume of the gelling elements but is caused by the formation of a network.

Effects of various factors which influence the process of gelation, on the intensity of scattered light, expressed in the form of the Tyndall number, have been systematically investigated by Mardles [74] during the reversible sol-gel transformation of cellulose acetate in benzyl alcohol. He finds that the Tyndall number is a function of the mechanical treatment and the rate of gelation. Further, it varies with time, temperature and the concentration of cellulose acetate. The Tyndall number-temperature curves reveal the existence of a maximum gelation temperature while the Tyndall number-concentration curves contain a maximum which decreases with rise of temperature.

The measurements of intensity and depolarization of scattered light have also been made during the reversible sol-gel transformation of agar-agar by Krishnamurti [75] whose results also point to the existence of a maximum gelation temperature. Further he finds that there is practically no change in the Tyndall number with time at and above 40°, but at and below 35° it increases with time until a constant value is reached, and that the particles in the gel state are bigger or greater or both than in the sol state.

A new aspect of the subject of scattering of light by colloids has been developed recently in the laboratories of Professor Sir C. V. Raman. Subbaramiah and Krishnan [76] have shown that in order to obtain information regarding the size and shape of particles in the colloidal state it is not sufficient to measure only the intensity and depolarization of the scattered light. They suggest that it is necessary to obtain the values of the depolarization factors (ρ_u, ρ_v, ρ_h) for the light transversely scattered by a colloidal system with incident light unpolarized, vertically polarized and horizontally polarized. The application of this method has been extended by Subba Ramaiah to the study of the phenomenon during the sol-gel transformation of silicic acid, stearic acid and sodium stearate[77]. He finds that a continuous increase in the micellar size takes place during the sol-gel transformation of silicic acid and this increase continues even after the formation of a rigid gel. The micellar size is greater in alkaline gels than in the acidic ones of the same concentration.

Refractive index measurements of systems which set to a gel have been made by a number of workers in the sol and the gel states mainly with a view to determine the transition temperature. Miss Laing and McBain [2] employed this method to examine the nature of aqueous solutions of sodium oleate in the three characteristic colloidal states and found that the sol and the gel forms are identical with respect to the refractive index.

Mardles [78] obtained indications of change of refractive index during the reversible sol to gel transition of cellulose acetate in benzyl alcohol. Mathur [79] also found that the refractive index increases rapidly as a solution of sodium oleate in pinene is cooled and reaches almost a constant value when the gel is set. The refractive index changes considerably with the temperature of setting but with the change in concentration of sodium oleate the effect on the refractive index is not appreciable.

No work seems to have been done on the changes in the refractive index of the inorganic gel-forming mixtures during the process of gelation. Some observations have been taken during the setting of a few gels and it has been found that this property does not undergo any appreciable change during the gelation process. However, Joshi and co-workers [80] who are the first to employ the refractive index method for the study of

the kinetics of the coagulation of sols by electrolytes have found zonal changes in this property with time.

The measurement of the extinction coefficient during the process of gelation seems to have been done mainly by Prasad and co-workers [81] and Prakash [82]. The former studied the changes in the extinction coefficient of silicic acid gel-forming mixtures during setting and found that the extinction coefficient-time curves for the acidic mixtures are S-shaped while those for the alkaline mixtures are smooth rising ones. Prakash has examined several other inorganic gels by this method.

The transparency or opacity method was first introduced by Mukherjee and co-workers [83] for the study of the kinetics of coagulation of sols by electrolytes. In their earlier work they measured the changes in the intensity of light transmitted through the coagulating system in various spectral regions but later on these changes were measured by means of a thermopile which was subsequently substituted by a photo-cell by Desai and co-workers [84]. The thermopile method was employed by Prasad and Hattiangadi [22] to study the kinetics of the formation of silicic acid gels. They found that the curves obtained on plotting the deflection differences against time are smooth and hence confirmed that gelation is one continuous process. The deflection differences reach a constant value after some time, which they take to be the time of setting of the gel. The changes in the deflection differences at various intervals have been found to be remarkably influenced by the alkalinity or acidity of the mixtures and the addition of non-electrolytes and electrolytes.

Desai's photo-cell method has been recently modified by Prasad and Modak [85] who have magnified the deflections of the galvanometer several times so that even the minutest changes in the intensity of the transmitted light may not go unnoticed. Employing this arrangement for the study of changes accompanying the process of gelation of stannic phosphate and zirconium hydroxide gels they find that the opacity-time curves are smooth S-shaped and these get shifted by a change in the concentration of solutions employed for the formation of gels. The probability of any error creeping in the above arrangement due to fluctuations of the current feeding the source of light and of the voltage applied to photo-cell, has been removed in the apparatus recently devised by Gogate [86] at the Royal Institute of Science. Further, by using a compensated photo-cell system this apparatus has been adapted to read directly the opacity changes taking place in a gelating system during setting.

(E) Syneresis, Drying, Imbibition, Hysteresis in Sorption and Swelling

Some gels exhibit the property of exuding liquid when they are allowed to stand for some time. This phenomenon

which is known by the name of syneresis was first observed with gels of silicic acid [87] but later on Ostwald [88] pointed out that it is shown by gels of nearly all substances which have widely different properties. The liquid exuded during the syneresis of geranin gels has been examined by Liepatoff [89] and is found to consist of small quantities of the dye which is present as single or double molecules.

The velocity of syneresis has been quantitatively studied by Liepatoff [89], Mukoyama [90], Fergusson and Appleby [91], Bonnel [92], Mathur [93] and others. For this purpose different methods have been employed to determine the amount of liquid exuded by a gel at different intervals of time. The influence of various factors, such as, the free surface, the concentrations of the constituents of the gel-forming mixture, the hydrogen-ion concentration, the presence of the added electrolytes and non-electrolytes, the temperature and other factors, on the syneresis has been exhaustively studied by some of the workers mentioned above and by Prakash and Dhar [94]. The results obtained have been critically examined by Kuhn [95] who concludes that certain gels show increased syneresis with increasing concentration whilst other gels behave in the reverse way. But there is no general rule regarding the influence of temperature on the degree of syneresis which is very sensitive to the presence of small amounts of additive agents. In general the syneresis is greater when the gel is in the least stable state.

The liquid contained in the gel can be removed by the process of drying or desorption. The first important investigation on the drying of gels was made by Van Bemmelen [96] whose experiments are considered as classical on the subject. He determined the loss of water suffered by silicic acid gels when they are dried to extreme limits and found that the contraction in volume of the gel is accompanied by changes in its transparency. Bemmelen's method of study was improved by Anderson [97] and Zsigmondy and co-workers [98] who observed changes of direction in curves obtained on plotting the amount of water held by one gram of silica against vapour pressure of the gel, at stages corresponding to the changes in its opacity. Further, they developed a mathematical expression to calculate the radii of capillaries in the silicic gel at different stages during drying. Similar investigations have been made on gels of several metal oxides. Desai [99] has shown that the rate of loss of water by silicic acid gels is least with neutral ones and increases with an increase in the acidity or the alkalinity of the gel-forming mixtures.

Fells and Firth [100] observed that when the rod of a gel of silicic acid prepared from sodium silicate and hydrochloric acid is allowed to dry under certain conditions, it contracts in volume and is surrounded by fine long needles jutting out of the dried rod. On analysis these were found to consist of sodium chloride

and their X-ray examination revealed that they possessed nearly the same structure as observed in perfect crystals.

The behaviour of gelatin gels on drying has been found to be different from that mentioned above. These gels shrink but do not show any changes in opacity at any stage during drying and there is no evidence of pores developing in the dried gel. Hatschek [101] has made an interesting study of the drying of gelatin gels made into various shapes and permanently deformed or bent before drying. He finds that drying increases the torsion considerably and a cylinder containing 10 to 15% gelatin first assumes the shape of a barrel with convex ends and finally that of a single shell hyperboloid with concave ends.

The dried gels of silicic acids and of other metal oxides, take up gases and vapours of liquids and although the amount sorped is in equilibrium with the pressure of the gas or the vapour, the sorption (hydration) isothermal is distinctly lower than that observed during desorption (dehydration), that is, the liquid content of the gel at any given pressure is smaller during sorption than during desorption. This has given rise to the phenomenon of hysteresis in sorption. The existence of the hysteresis loop has been observed by Van Bemmelen [96], Zsigmondy [98], Anderson [97], Allmand and co-workers [102], McBain [103], Foster [104] and several others and some of them have shown that hysteresis is real and persists even after drastic degassing of the gel surface. Recently, this phenomenon has been exhaustively studied by Subba Rao [105] by means of McBain-Baker quartz fibre spring balance with dried silica and metal oxide gels which were suitably activated. He has shown that the loop is a permanent one and is reproducible any number of times. Thus, for example, he has reproduced the loop in silica gel-water at the 19th cycle and in titania gel-water at the 32nd cycle. Further, he has succeeded in scanning the loops by traversing them from various intermediate points on the main sorption and desorption curves and has thus established the permanency and the reproducibility of the hysteric loops.

A similar study has been made by Subba Rao [106] of rice-water, dhal-water, gum arabic-water systems which also exhibit the phenomenon of hysteresis initially but the loop disappears on progressive sorption and desorption. However, a series of sorptions and desorptions of carbon tetrachloride by the activated rice grain shows a permanent and reproducible hysteresis loop.

The imbibition of water by gels of gelatin and of some other substances is accompanied by an increase in volume and is called swelling. A considerable information is available regarding the velocity of swelling of gels and the properties exhibited by the swollen gels. Thus, for example, it is known that an appreciable amount of heat is evolved during swelling and the swollen gels exert a pressure (swelling pressure) which is fairly high and is related to the concentration of the disperse phase. An extensive

investigation by Proctor and collaborators [107] has revealed that the swollen gelatin gels consist of two forms of gelatin, the unionized isoelectric gelatin and the ionized salt which may be gelatin hydrochlorides or sodium gelatinates.

The amount of water taken up by gelatin gels not only depends upon its concentration and its previous history but also upon the hydrogen-ion concentration of the solution from which imbibition takes place. Kunitz [108] has shown that gelatin gels, up to ten per cent concentration, contract when placed in a solution of pH 4·7 but swell if the concentration of the gel is greater. He considers that the shrinkage in water is similar in nature to syneresis and suggests that the two phenomena should be considered as synonymous. Hardy [109] has suggested that the exudation of liquids by gels should be considered as positive syneresis and the imbibition as negative syneresis.

(F) Diffusion and Chemical reaction in gels

Early workers had held the opinion that the rate of diffusion of dissolved substances in gels is practically the same as in liquids. However, later investigations in this direction have shown that this behaviour is true only in certain limiting cases, the concentration of the gel exerting a great influence on the rate of diffusion of electrolytes [110, 111]. Further, substances of high molecular weight have been found to diffuse very slowly in gels while for colloidally dispersed substances the gels serve as filters which allow only the dispersion medium to pass through.

Recently, Friedman and co-workers [112] have studied the diffusion of several non-electrolytes in gels of gelatin, agar-agar and cellulose acetate in benzyl alcohol, by a new technique which has several advantages over those employed previously. In this method a gel is covered with an equal depth of water which is kept stirred continuously and the diffusing substance is contained either in the gel or in the outside water. Small samples of water are taken out periodically and analyzed by means of the Immersion Refractometer. Increase in the concentration of the gel has been found to decrease the rate of diffusion markedly; the decrease is linearly related to the increase in concentration in the case of agar gels. The diffusion coefficients have been calculated from an expression developed by Weaver [113] and their values in water and in gels are related by the equation,

$$K_{H_2O}=K_{gel}\left(1+\frac{2{\cdot}4r}{R}\right)(1+\alpha)(1+\pi)$$

in which r is the radius of the diffusing molecule, R the radius of the pores of capillaries in the gel, α the correction factor for viscosity and π the correction factor for mechanical blocking. Patrick and Allan [114] have studied the diffusion of various

electrolytes through silicic acid gels and have found that their results are not in agreement with Nernst's theory of diffusion but can be satisfactorily explained on a theory developed on the basis of electro-kinetic potential.

It has been found that a number of reactions and crystallizations which will not otherwise take place, proceed fairly smoothly in the gel media. In silica gels, cupric ions are reduced to cuprous state and even to metallic copper when treated with glucose [115] and basic lead acetate is reduced to metallic lead by tin [116]. The crystals of mercuric iodide and bromide are obtained in elongated tetragonal form when the silica gel containing potassium iodide is flooded with mercuric chloride [117].

A remarkable phenomenon is, however, noticed in certain cases in which the precipitate formed by a chemical reaction in gel media is deposited in a number of separate bonds or layers or rings. The rhythmic or banded precipitation, first observed by Liesegang and known after him, is observed in Nature in systems of very different origin, namely, in rocks, vegetable matter, plants and animals. In chemical reactions which give rise to such a precipitation it is necessary to use proper concentrations of the reactants and suitably adjust the hydrogen-ion concentration of the system. Mitra [118] has recently shown that periodic precipitates are also formed in the absence of a foreign gel during the coagulation of sols of ferric phosphate, ferric arsenate and ferric borate under suitable conditions.

Several attempts have been made to obtain a mathematical expression relating the distances between the different bands and the several factors involved in their formation. Empirical relations have been obtained by Lakhani and Mathur [119] between the distances of rings of the same ordinal number and the concentration of the diffusing substance, by Mikhalev, Nikijorov and Shemyakin [120] between the distance of the rings and the actual spreading velocity, by Suzanne Veil [121] between the order number of the principal rings and their distances. A theory based on the diffusion law has been recently derived by Hughes [122] and it seems to account satisfactorily for the distances between the several bands.

Various theories have been put forward to account for the origin of the Liesegang phenomenon. The older theories were based on the supersaturation and crystallization of the banded substance and these were followed by theories which aim at explaining the phenomenon from the colloid-chemical point of view. According to these theories, the main rôle is played by the adsorption by the precipitate either of the substance present in the gel or of the sol of the precipitated substance.

On the other hand, some workers have suggested that the Liesegang phenomenon should be explained on the consideration of de Broglie waves associated with the movement of the precipitating agent. Christiansen and Wulff [123] have shown that

the velocity calculated from de Broglie's equation is in good agreement with the experimental value for several precipitates. They have also applied the Schrödinger equation to these systems and have developed a theory which seems to account for the observed phenomenon. Raman and Subbaramaiah [124] have also observed a phenomenon with Liesegang precipitates of silver chloride and silver chromate in gelatin, and they consider this to be unmistakably in the nature of interference effects.

Theories of gel-formation and gel structure

The above-mentioned and several other investigations of the various properties of a number of gels have given birth to many theories of the structure of gels, but most of them are mere modifications introduced in the general theories, to suit the behaviour of particular gels. Three general theories of gel structure have been recognized and these are: (1) solid solution theory, (2) liquid-liquid theory, and (3) liquid-solid theory. None of these explains satisfactorily the phenomena observed during the process of setting and the properties of all classes of gels when set.

The methods of preparation of gels indicate that the first condition or stage for the formation of gels is that the gelling substance should be obtained in the sol condition; this state may only be a temporary one in some cases. This can take place either by mechanical action and ion adsorption from a medium which does not exert any appreciable solvent action. The density of electrical charge on colloidal particles formed from ionic solutions may be positive or negative but it should not be high as otherwise discrete flakes which may be gelatinous would be formed. The condition of low density of charge is probably realized in systems in which the gelling substance is formed as the result of chemical reaction. If, however, this condition does not exist, it is created in some cases by the addition of electrolytes and in other cases by prolonged dialysis. The condition of prolonging the dialysis is essential, for Desai and co-workers [125] have shown in a series of papers that the density of charge on colloidal particles, determined from the cataphoretic velocity, increases during the earlier period of dialysis and subsequently decreases.

Another important condition for the formation of a gel is to obtain a sufficient amount of the gelling substance in a supersaturated state. The importance of this condition can be realized from the fact that under given conditions certain concentration limits are prescribed for every gel. If these are exceeded, no gel-formation takes place. Von Weimarn [126] has expressed the results of his investigation on the effects of concentration in the form of an equation which leads to the inference that gel-formation takes place only when the factors involving

viscosity and the degree of supersaturation are large and the solubility of gelling substance is small.

The second condition of gelation consists in the coalescence or coagulation of the particles of the sol of the gel-forming substance at a velocity which is not too great[127]. It has been shown by Hurd, Raymond and Miller[42] that the setting time of a particular mixture giving rise to silicic acid gel from a positively charged sol, is decreased to a greater extent by the addition of sodium chloride than in the presence of the same quantity of sodium sulphate. This observation must raise doubts regarding the nature of coagulation involved in the process of the formation of inorganic gels. But the study of the viscosity and opacity changes during the coagulation and gelation of a concentrated sol of stannic hydroxide under not widely different conditions has yielded results which are similar in nature. De Jong[128] has also concluded that gelation of agar sol has all the characteristics of flocculations. These observations together with the fact that same methods are employed for the study of kinetics of coagulation and gelation lead one to conclude that the agglomeration of colloidal particles in inorganic gels takes place by a mechanism which is analogous, if not identical, with true coagulation.

The process of the formation of large entities is accompanied by very strong absorption of the surrounding medium so that the ultimate particles of the gel are so heavily solvated that hundreds of molecules of the medium are associated with one molecule of the gel-forming substance. These conclusions have been confirmed from the calculations made from Hatschek's formula for the determination of the degree of hydration.

The third stage consists in the formation of specific structures which are fairly complicated. During this process the complete immobilization of the fluid takes place which, according to Ostwald, is the most important characteristic of a gel. It is probably at this stage that rapid changes in the viscosity and surface tension of the gel-forming system take place. Nothing definite is known regarding the forces which bind the ultimate particles of the gel together; it has only been surmised that they are of the same nature as residual affinities since they can be overcome in the same manner as in melting.

The above discussion reveals that gels are made up mainly of two phases. Ostwald pictured that these two phases are liquids and on this basis put forward the emulsion theory of gel structure. On critical examination Hatschek has shown that this theory is faulty since the mechanical properties of a liquid-liquid system do not correspond to those of true gels.

The other two theories assume that a gel is made up of solid and liquid phases. The ultra-microscopic observations and the method of Tyndall Effect have indicated that the solid or the semi-solid phase is present but it exists in such a fine grained

structure that it is not visible by these methods. The solid solution theory only states that the dispersion medium is held in the gel in the form of a solution in the solid colloid and does not deal further with the structure of gels. The liquid-solid theory considers that the structure of gels may be (i) cellular, or (ii) fibrillar or micellar.

According to the first theory the structure of gels is made up of cells built of the solid phase, and these hang together at certain points so as to form a network. The liquid phase of the gel is held in the form of droplets in this cellular frame work. The cellular structure has been actually observed in the case of some gels (Bütschli, silicic acid) and the microscopic observation of Hardy [28] also lead to the conclusion that gelatin gels form a framework which is an open structure and which holds the fluid phase in its interstices. This theory accounts for the elasticity of gels but cannot provide satisfactory explanation for the phenomena of syneresis, swelling and dehydration and the absence of any change in the electrical conductivity during setting [129].

The fibrillar theory was first put forward by Nägeli [130]. It postulates that gels are made up of fibrous structure formed of the solvated solid phase and the liquid phase is contained in the pores of these fibres or aggregates, both phases being continuous. Several views are held regarding the mechanism which gives rise to the fibrils. They may be either formed by the mechanical agglomeration (following coagulation in the case of inorganic gels) of the colloid or may consist of very large polymerized molecules or the fine crystals of the gel-forming substance.

In the case of the gelatin gels the sol, according to Bogue [131], already contains slightly hydrated molecules united into short threads. On cooling the sol, these threads increase in length, swell, lose freedom of motion and cohere with each other. Miss Laing and McBain [2] also consider that during gelation the particles of soap sols stick together in filamentous structure. Barrat [132] has summed up the conclusions regarding the structure of elastic gels in a statement that they are made up of a network of a mass of intersecting fibrils which are at first microscopic and later become ultra-microscopic.

In the case of silicic acid gel the simple molecules which are first formed [133] change over to complex molecules (β-silicic acid) probably by condensation accompanied by the splitting of water, and the threads are made up of polysilicic acid molecules. Hurd [134] has suggested that theoretically the process of condensation should occur more readily if an equal number of the simple molecules of silicic acid ionize, giving rise to positive and negative ions [$Si(OH)_3^+$ and $SiO(OH)_3^-$] and if the collision between them occurs more frequently. The probability of this mechanism is supported by the amphoteric character of silicic acid. The polysilicic acid molecular chains which are inter-

connected in the three dimensions in the gel, are neither large nor are they of sufficient density and hence are not visible in the microscope. This process of the formation of the fibrils explains the absence of a change in the electrical resistance of the silicic acid gel during setting and the non-thixotropic behaviour of these gels.

It has often been suggested that the solid phase in a gel is crystalline and the phenomenon of gelation is similar to crystallization. Krejci and Ott [135] have found a cristobalite pattern by an X-ray analysis of the freshly prepared gels of silicic acid. But there are several gels in which there is no evidence in favour of the existence of crystalline structure, although a tendency towards such a structure is probably indicated. Hardy [136] concludes, 'The process of gelation has many points of resemblance to crystallization but the masses which have all the appearance of crystals are not crystals'.

The lenticular form of bubbles generated during gelation indicate that there exists a force in gels which tends to orientate the threads. In this process they cause further contraction and thereby affect the squeezing out of the fluid through the capillaries. This is manifested as syneresis. During the dehydration of gels also the fluid is removed through the capillaries which shrink in size and get filled up with air in well-dried gels. Syneresis and dehydration seem to be related to each other, probably on account of the nature of capillaries, as both of them have been found to be minimum in the case of silicic acid gels near the neutral point. When the dried silicic acid gels are moistened with water, the swelling of the outer walls of the gels causes a strain which makes the gels crumble violently into pieces. This phenomenon was first observed by Bhatnagar and Mathur and is described by Ostwald in *Kolloid Zeitschrift* as Bhatnagar-Mathur Effect [137] which has been studied systematically at the Lahore Laboratories.

Diffusion through gels also takes place through the fluid which fills these capillaries. They are wide in dilute gels and hence the rate of diffusion in them is the same as in the free dispersion medium. But the increase in the concentration of the gel narrows down the capillaries and hence diminishes the amount of the fluid in them and thereby decreases the quantity of the substance diffusing in.

The size of the pores determined from the dehydration data in the case of variously dried silica gels has been found to vary between $2{\cdot}75\mu\mu$ and $1{\cdot}376\mu\mu$ between the two opacity points. Friedman and co-workers found from the diffusion data that the radii of the pores in different gels vary from $1m\mu$ to $5m\mu$. These data confirm Pauli's suggestion that the gels are ultra-porous. The average value of the interval between two threads has been found by Kraemer [138] to be of the order of 100 millimicrons.

Subba Rao[105] has put forward a concept that the capillaries in the porous gels are in the form of cavities with constricted ends. This concept offers not only a satisfactory explanation for the existence of the hysteresis loop but also explains the phenomena of the scanning and the drift of the loop. The disappearance of the loop on progressive sorption and desorption in elastic gels, such as those of rice and dhal, is explained on the consideration that the cavities swell on the imbibition of water, become elastic and hence lose their power of entrapping water.

The length and number of the fibrils in a gel are responsible for its elasticity. Poole[55] has developed a mathematical theory for the behaviour, under stress, of a structure composed of a mesh of cylindrical threads and found that the experimental elasticity-temperature-concentration relations for gelatin and cellulose acetate gels are in qualitative and approximately quantitative agreement with the theory. The time factor or 'creep' is mainly due to the reversible flow of the liquid phase in the interstices of the solid phase.

The fluid contained in gels is probably a solution of the gel-forming substance in the dispersion medium. Some of it is associated with the micelles and the rest is contained in the interstices of the fibrils. These have been considered as 'fixed' and 'free' fluids[139]. It is the free or interstitial fluid which comes off first during desorption of gels. The rigidity of gels has been shown to depend upon the relative amounts of the free and fixed fluid contained in them.

Freundlich, Ostwald, Hauser and Kistler[140] consider that in thixotropic gels the water molecules are orientated and form thick rigid envelopes round the particles of the gel. These lyospheres are destroyed by shaking and reformed on allowing the gel to stand. But Russel and Rideal[141] have collected evidence in favour of the view that the ultimate particles of the thixotropic gel-forming material are anisotropic or anisometric or both and the charge and the adsorbed water molecules are unequally distributed. According to them the structure of thixotropic gels is made up of these entities which are regularly orientated and the mechanical stress only destroys this orientation.

The anisometric nature of the micelles has been indicated in sols of cellulose derivatives by X-ray methods. Subba Ramaiah[77] has also found from his optical method that the micelles in the rapidly setting silicic acid gels possess a spherical asymmetry and the spherical symmetry of the micelles in the slow setting systems decreases due to an orientation subsequent to the setting. Freundlich also states that it is undeniable that the particles in many thixotropic systems are non-spherical.

It would appear from this survey that the fibrillar theory is in harmony with most of the characteristic properties and varied

phenomena shown by gels. It explains satisfactorily the elasticity, viscosity, syneresis, swelling, dehydration and hysteresis, diffusion and optical and ultra-microscopic phenomena. This theory has the adherence of most of the workers on the subject of gels, although it cannot be assumed *prima facie* that all gels have the same architecture.

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SECTION OF GEOLOGY

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Presidential Address

(*Delivered on Jan. 3, 1941*)

PALAEOGEOGRAPHICAL REVOLUTIONS IN THE INDO-BURMESE REGION AND NEIGHBOURING LANDS.

(VINDHYAN TO DEVONIAN)

INTRODUCTION.

I deeply appreciate the honour you have done me in electing me to preside at the Geology Section of the Indian Science Congress.

We meet to-day at a critical juncture in the world's history: under the shadow of a great war and at a period of strife and restlessness. It is therefore, perhaps, in the fitness of things that I should select the title Palaeogeographical Revolutions as the subject of my address. Such far-reaching changes are not merely the heritage of social or political systems, but are also inherent in our geological systems, in our great continents and the restless oceans.

THE CHANGING FACE OF THE EARTH.

The earth pulsates with life. The once lofty snow clad mountain ranges, like the Vindhyans, have been levelled and humbled by the impact of weathering agents. The Poles have wandered far and wide through geological ages and there is reason to believe that during the early Gondwana period the South pole was situated in the middle of the Indian Ocean, while the North pole lay near Tulterango Mexico.[1] On the contrary the great ice-bound polar regions supported a warm water coral fauna during the Palaeozoic and a warm sun blazoned upon a luxuriant tropical vegetation during the Mesozoic era. This is not all. Even the great continents having played their part in the earth's equilibrium founder and disintegrate; the seas become

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sedimented by the passage of time: the face of the earth changes. The result of these phenomena is a redistribution of land and sea, of plant and animal life leading, in short, to Geological and Geographical revolutions. It is about these changes that I propose to speak to-day.

THE BASIS OF PALAEOGEOGRAPHIC RESTORATION.

Before considering the Vindhyan landscape, with which I propose to commence, let us for a while examine the basis upon which the restorations of ancient geographies are founded. The only basis of exact correlation is the occurrence of identical species of animal or plant fossils in strata of marine or continental origin as the case may be. Our conclusions are true and exact in the measure in which our observations and identifications are accurate. So much so that when data are reliable it is possible to institute exact correlations in strata separated by hundreds and even thousands of miles, and we are enabled then to determine the extent of inter-marine communications. Few more remarkable instances of this type could be cited than that of the Middle Devonian (Eifelian) faunas of the Shan States and Germany which, though separated by several thousand miles, are specifically identical and are a clear indication of a free marine connection between Southern Asia and Northern Europe.[1]

But the task is not quite so simple and many difficulties beset the investigator in this field. There are many anomalies which are difficult to explain. The reason perhaps is that the most obvious explanations are not always the most reliable. For example, whenever the marine faunas in two regions, even in close juxtaposition, are unaffined, our first instinct is to interpolate a land barrier, as we have done in the case of the Cretaceous Seas of Central and Western India (Bagh Sea) on the one hand and Southern India (Trichinopoly Sea) on the other. Referring to the accepted contrast between the Bagh and Trichinopoly Cretaceous beds Wadia [2] observes that they differ

> 'As widely as it is possible for two formations of the same age to differ'

and that this contrast

> 'Denotes isolation of the two seas in which they were deposited by an intervening land barrier of great width, which prevented the inter-sea migrations of the animals inhabiting the two seas'.

Recent identifications of certain Bagh fossils, however, tend to show that this land barrier was probably not so effective and must have broken down during periods of marine trans-

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[1] La Touche, T. H. D. Geology of the Northern Shan States, *Mem. Geol. Surv. Ind.*, Vol. XXXIX, Pt. II, p. 239, 1913.

[2] Wadia, D. N. Geology of India, p. 207, 1939.

gression for among the Bagh fauna occur *Protocardium pondicherriense* D'Orb., *Cardium* (*Trachycardium*) *incomptum* Sow., *Macrocallista sculpturata* (Stoliczka) and *Turritella* (*Zaria*) *multistriata*, which are characteristic of the Upper Cretaceous of Southern India. A Nautilus—*N. labechei* D'Archiac et Haime—from the *Cardita beaumonti* beds of Sind appears, according to Blanford,[1] 'Indistinguishable from *N. bouchardianus* found in the upper Cretaceous Arialur beds of Pondicherry'. Our idea of the Cretaceous palaeogeography of India therefore needs modification, though perhaps only in detail.

Differences between the faunas (or floras) of two regions need not necessarily indicate a land (or sea) barrier. Variation in the physical conditions such as temperature, depth, relative salinity, direction or strength of ocean currents of intercommunicating marine regions may be just as effective barriers to the migration of marine faunas as land barriers. But our knowledge has not yet reached a stage when the effects of these are readily traceable in fossil faunas, though the occurrence of ancient coral reefs indicating known conditions of depth and temperature, of stunted marine faunas often indicating excess of salinity, of the presence of boreal elements (modern representatives of which inhabit the cold waters) of xerophytic plant types like the Lower Cretaceous species *Weichselia reticulata*[2] indicating proximity of arid conditions, are often instructive and interesting. Similarly differences in the relative heights of neighbouring regions may effectively bar the intermingling of floras and if these differences are considerable, as in the case of high mountain ranges, sharply defined floral zones may result without the interpolation of actual physical barriers.

In a certain measure the immediate environment must always leave a marked local impress upon faunas and floras, but certain widespread or cosmopolitan types sometimes weave a thread of uniformity through the otherwise differing life-provinces, though these may be suggestive only of remote connections. It is the more characteristic and vertically confined types that are the more useful for palaeogeographic restoration. Thus the Lower Devonian fauna (Hercynian facies) characterized by *Tentaculites elegans*,[3] the Middle Devonian fauna characterized by *Calceola sandalina* and its associates, the Upper Devonian fauna with *Spirifer verneuili* give us clues to the intercommunication of the seas during these times. The genera

[1] Blanford, W. T. Geology of Western Sind. *Mem. Geol. Surv. Ind.*, Vol. XVII, Pt. I, p. 36, 1878.

[2] Sahni, B. The occurrence of *Matonidium* and *Weichselia* in India. *Rec. Geol. Surv. Ind.*, Vol. 71, Pt. 2, p. 156, 1936. See also Gothan, W. *Jahrb. Preuss Geol. Landesanst*, 43, pp. 772–777, 1921.

[3] The question of the age of this Hercynian fauna in the Shan States will be discussed in detail later.

Glossopteris and *Gigantopteris*[1] both widespread forms give the extent of the continents during Permian times. Particular importance therefore attaches to forms that are widespread yet confined to certain regions and horizons.

There is another very important factor which has probably been overlooked much oftener than we realize. I incline to the view that the supposed effective barriers which have been presaged in some cases where faunal differences are manifest are probably hypothetical. *Such differences may be due to the fact that we are not dealing with strictly contemporaneous faunas, but with faunas of varying ages within the same geological system.* We may even be dealing with faunas that are insufficiently known or indifferently preserved so that the extent of affinities with other faunas may be exaggerated or minimized because of incomplete determination.

Thus it is often stated that while the Ordovician fauna of the Northern Shan States bears a striking relationship to the North European fauna, the Himalayan fauna appears to be affined to the American Ordovician fauna and therefore it is argued that an effective barrier separated these regions. But in my opinion this explanation is unsatisfactory, and the differences between the poorly preserved Himalayan faunas and the Shan Ordovician faunas are probably due to lack of absolute contemporaneity rather than to imaginary barriers. However, this problem will be further considered later under the Ordovician section. Likewise the greater affinity of the Cambrian faunas of Iran with the far Indo-Chinese rather than

[1] The *Gigantopteris* and *Glossopteris* floras although now in close juxtaposition are quite distinctive. It has been claimed that their present position is the result of drifting towards each other of the continents supporting these floras (Wegner's hypothesis of continental drifts). This explanation however does not seem altogether satisfactory, for if the sea separating them was a narrow one then a fair intermixture would be inevitable, which is not the case. If, on the other hand, a wide geosyncline separated the continents then their drift towards each other would lead to puckering up of the geosynclinal sediments and a mountain range would result. The Eastern Assam and Arakan regions would at first sight appear to supply the requisite mountain range. But surprisingly enough the Eastern Assam and Arakan ranges which practically form the boundary between the *Glossopteris* and *Gigantopteris* floras do not contain any Permian or pre-Permian marine sediments; at least such are not exposed on the surface and we may perhaps conclude that there was no wide marine barrier between these palaeobotanical life-provinces. A more satisfactory hypothesis therefore appears to be that these floras lay in different contiguous climatic zones, which explains both the juxtaposition and distinctiveness of these floras. The palaeobotanical data, according to my brother Prof. B. Sahni, clearly indicate that the climatic differences between the two provinces are well marked, that the *Gigantopteris* flora is a warm climate flora and that the *Glossopteris* flora is a temperate flora, starting originally as a cold temperate flora. (See B. Sahni, *Journ. Ind. Bot. Soc.*, Vol. XV, No. 5, pp. 322-323, 1936, and E. Norin, Geol. Foren Stockholm Forh Bd. 46, Heft. 1-2, 1924.)

with those of the Salt Range which lay in the same pathway of migration, is in our opinion due not to any impassable land barrier but to difference in the relative ages of the Cambrian faunas of the first and last named regions.

Sudden bursts of migration and the apparent mingling of faunas of different ages often present baffling problems. One cannot cite a more striking instance than that of the Zebingyi fauna of the Shan States,[1] in which are co-mingled species of *Monograptus*, so typical of the Silurian, and *Tentaculites elegans*, equally characteristic of the Hercynian (Lower Devonian) facies of Southern Europe. The question then faces us, what is the age of the Zebingyi beds—Silurian or Devonian? for upon our reply will depend our conception of the distribution of seas during those periods. I shall endeavour to answer this question later.

Often there is wide divergence of opinion in the interpretation of evidence which may affect problems of palaeogeographic restoration. Thus the Namyau strata of the Shan States are relegated to the Trias by Frommaget [2] and others working in Indo-China, while I consider their Jurassic age unimpeachable.[3]

Of recent discoveries in Burma which affect the problem in hand reference must be made to the important find by Clegg [4] of certain foraminiferal sediments in the Second Defile of the Irrawaddy river. The Cretaceous [5] age of these sediments was proved by my identification of the genus *Orbitolina*. Apparently a single species, *Orbitolina birmanica* Sahni, is represented.[6] Reference may also be made to recent finds, during my surveys of the Shan States, of ammonite bearing Lower Triassic strata [7] (Na Hkyam beds) in the Northern Shan States as well as of Middle Devonian rocks [8] (Meso beds) in the Southern Shan States. The Na Hkyam beds constitute the only known record of the Lower Trias in Burma, while no other Middle Devonian rocks are known from the Southern Shan States.

But since some at least of these discoveries refer to the Mesozoic, we are not directly concerned with them here.

We may now revert to a consideration of the Vindhyan.

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[1] La Touche, T. H. D. *Loc. cit.*, pp. 163–170, 1913.

[2] Frommaget, T. *Bull Sérv. Géol. Indochine*, Vol. XVIII, Fasc. 5, pp. 19-20, 30, 1929.

[3] Sahni, M. R. *Rec. Geol. Surv. Ind.*, Vol. 71, Pt. 2, pp. 217–230.

[4] Clegg, E. L. G. *Rec. Geol. Surv. Ind.*, Vol. 72, pt. 4, 1937.

[5] Sahni, M. R. *Rec. Geol. Surv. Ind.*, Vol. 71.

[6] I provisionally assigned the topmost Barremian age to this species on account of its close relationship with *Orbitolina tibetica* Cotter. Further comparisons appear to indicate much similarity with *O. scutum* v. Fritsch and *O. trochus* v. Fritsch, of the Cenomanian. The possibility of the Burma orbitolines being Cenomanian cannot therefore be entirely overlooked.

[7] Sahni, M. R. *Proc. Twenty-fifth Indian Science Congress*, Part III, p. 114, 1938.

[8] *Ibid.*, pp. 114-115, 1938.

VINDHYAN PANORAMA.

It would perhaps be futile in the present stage of our knowledge to discuss the conditions of deposition of the pre-Vindhyan strata, for here we are much within the domain of speculation. I propose therefore to commence with the probable distribution of land and sea in Southern Asia during the Vindhyan period which coincides with the first flush of life on the earth, over 500 million years ago. Here too, I am afraid, we are on no certain ground, for we catch but stray glimpses of this ancient panorama, and the effort at restoration is like that of a painter endeavouring to restore a terribly mutilated old master. Still a clue here and there may be deciphered, or ancient landmarks, unmasked by the removal of the overlying mantle of rocks, fitted together like a jigsaw puzzle in restoring ancient geographies.

DISTRIBUTION, CORRELATION AND CONDITIONS OF DEPOSITION OF VINDHYAN SEDIMENTS.

The belt of Vindhyan sediments constitutes the highlands of Central India and extends from the Vindhyachal mountains in the west to Behar in the east. North of this belt extends the vast Indo-Gangetic plain—a trough of geologically recent origin, now filled up by masses of alluvium brought down by the Indo-Gangetic drainage system. The Deccan plateau forms the southern limit of these sediments.

Lithologically the Vindhyans of Central India are characterized by the development of highly coloured sandstones with a prevailing red or purple colour, by intercalations of gypsum indicating in general conditions of aridity or semi-aridity. Limestones occur in the lower part of the succession clearly indicating marine conditions.

It is a remarkable circumstance that the Cambrian strata of the Salt Range contain, in the lower part of the sequence, beds which betray a striking lithological similarity to those of the Vindhyans of Central India. There can be little doubt that these strata were deposited under identical conditions except that aridity was perhaps more marked in the Salt Range region than in the Vindhyan.[1]

The recent discoveries of Cambrian strata in Iran (Hormuz Series) and their striking lithological similarity with those of the Salt Range is likewise strongly suggestive of the extension of similar arid conditions westwards. Fox[2] lays stress upon this view when in reference to the Salt Range he says

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[1] Auden refers to the problems of Vindhyan climates and correlation (with the Cambrians) in a brief abstract (*Internat. XVII Geol. Congress, Abstracts*, p. 216, 1937). The full paper of which I had the privilege of seeing the MS. will, it is hoped, be published shortly.

[2] Fox, C. S. Progress Report for 1928.

> 'I would definitely connect these Vindhyan strata with those of the Punjab Salt Range. My experience in this region is in agreement with such a connection. The beds of the Salt Range, i.e. the Cambrian strata from the Salt pseudomorph beds down to the purple sandstone, and in my opinion, the saline series below, represent deposits of an arid region in a shallow sea. The same is in general true of the upper Vindhyans'.

In an interesting and important paper published in 1928 Fox expressed himself even more emphatically when in reference to the Salt Range Cambrian succession he said [1]

> 'All the deposits in this succession are suggestive of marine deposits in hot desert regions and thus have geographical relationship'.

Auden [2] from his experience of Vindhyan sedimentation in the Son Valley concurs in this view. And I think there can be no question about the occurrence of identical physical conditions in these regions during the periods named. But the crucial point we have to decide at the moment is, are the Iranian Hormuz Series, the Salt Range Cambrians and the Vindhyan strata contemporaneous?

Now the only basis of exact correlation is the presence of identical species of animal or plant fossils. In the Vindhyans of Central India the only fossil remains are circular, possibly (originally) lens shaped discs found by Jones [3] in 1908, in some black shales near Neemuch. These organic remains have created a storm of controversy. Jones himself thought them to represent *Obolella* or *Chuaria circularis*, described by Walcott from the pre-Cambrian rocks of Arizona or possibly the operculum of *Hyolithellus*. Walcott and Resser [4] of the Smithsonian Institution, Washington, regard them as primitive brachiopods related to *Acrothele*. Chapman [5] who made a detailed study of these fossils thinks they are 'possibly Atrematous and Neotrematous brachiopods' of early Cambrian or pre-Cambrian age, and created the genera *Fermoria* and *Protobolella* for their reception. Howell [6] however casts doubts on these views and is more in favour of their plant origin. I re-examined [7] Chapman's types and other material and came to the conclusion that these fossils did not possess any characters which recalled primitive

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[1] Fox, C. S. A contribution to the Geology of the Punjab Salt Range. *Rec. Geol. Surv. Ind.*, Vol. LXI, Pt. 3, p. 173, 1929.

[2] Auden, J. B. Vindhyan Sedimentation in the Son Valley. *Mem. Geol. Surv. Ind.*, Vol. LXII, Pt. 2, p. 223, 1933.

[3] Jones, H. C. *Rec. Geol. Surv. Ind.*, Vol. XXXVIII, p. 66, 1909.

[4] General Report. *Rec. Geol. Surv. Ind.*, Vol. LX, p. 18, 1927.

[5] Chapman, F. *Rec. Geol. Surv. Ind.*, Vol. LXIX, Pt. I, pp. 109–120, 1935.

[6] General Report. *Rec. Geol. Surv. Ind.*, Vol. LXI, pp. 21-22, 1929.

[7] Sahni, M. R. *Rec. Geol. Surv. Ind.*, Vol. LXIX, Pt. 4, pp. 458–468, 1935.

brachiopods. I considered their affinities uncertain and therefore proposed the family *Fermoriidae* for them: one specimen—the only one which looked like one of the *Atremata*—was renamed *Vindhyanella.*

Dr. Howell in a personal communication to me has expressed accord with my views and considers the Vindhyan forms related to some similar remains discovered in the United States, in rocks of ?pre-Cambrian age. Although indefinite comparisons have been suggested with early Cambrian forms' none of these organic remains from the Vindhyans are related to the fossils from the known fossil horizon in the Cambrian of the Salt Range or Iran. In the absence of fossil evidence it is impossible to suggest any precise correlation of the Vindhyans of Central India with the Salt Range Cambrian succession or the Hormuz Series of Iran. There is indeed no consensus of opinion whether the Cambrian strata in the Salt Range are of Lower or Middle Cambrian age, though evidence is now veering towards the latter view. And the supposed Lower Cambrian age of the Iranian (Hormuz) strata is now definitely proved to be Middle and Upper Cambrian. It would appear that the correlation of the Vindhyans with the Salt Range and Hormuz Series was tempted by the supposed Lower Cambrian age of these strata and their marked lithological similarity supported possibly in some measure by the supposed primitive brachiopod affinities of the Vindhyan fossils. But since the only known Vindhyan fossils have been shown not to be brachiopods of Lower Cambrian affinities or not even brachiopods at all, I think a correlation between the Vindhyan and Cambrian strata seems unjustifiable though one may certainly concede that the physical conditions remained unchanged from the Vindhyan to Cambrian times. Moreover, since the Vindhyans are so little metamorphosed, the absence of other fossils such as tribolites or pteropods seems difficult to explain, especially when the conditions of deposition were identical, at least in part. It is in my opinion unlikely that if the Vindhyan, the Salt Range and Iranian strata belonged to the same province of sedimentation, the one would be so bereft of life while the others teemed with it.

SOUTHERN AND EASTERN ASIA.

Let us now examine the conditions prevalent further east, in the central and eastern Himalaya, in Burma and China.

Our ideas concerning the Vindhyans of the Himalayan region have undergone much change since Vredenburg[1] suggested that

> 'amongst the mountains of Northern India, the Vindhyans are represented by the Deoban Series near Chakrata, the Krol Series and

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[1] Vredenburg, E. W. Geology of India, p. 34, 1910.

Infra-Krol of the Simla area, the Haimanta of the Northern Himalaya, the Attock Series of the Punjab, and a portion of the Panjal System in Kashmir.

' Of these extra peninsular occurrences, the Attock Series corresponds more particularly with the Lower Vindhyan, the Krol Series more particularly with the Upper Vindhyans. The Haimanta probably includes both.'

The fossil fragments of the genus ? *Chonetes* found, according to Das-Gupta and Vredenburg,[1] in the Krols near Solon (Simla Hills) appear to indicate that they are much younger than Vindhyan strata and are probably of about Permian age. Auden[2] disagrees with this identification completely (as did Hayden earlier) and even suggests that the supposed *Chonetes* from the supposed Krols is in fact an Oyster from the Subbathu series! I have not seen this *Chonetes* and am therefore unable to express an independent opinion on this identification, but in regard to the field relations of the beds under consideration, I am sure, my colleague's observations can be entirely relied upon. However, the main fact from my viewpoint is that at all events the Krols are post-Vindhyan, a view already expressed by Pilgrim and West[3] in 1928.

We are then left with the unfossiliferous sediments variously grouped under the names Baxa, Jaunsar, Attock and Simla slates. Are these to be correlated with the youngest of the Purana sediments, namely, the Vindhyans? Are they even to be correlated amongst themselves? There is at present no satisfactory reply to these queries, but their correlation with some part of the Vindhyans appears at least a plausible, even though speculative hypothesis. If we accept this correlation we may visualize the extension of a northern Vindhyan sea over certain parts of the lesser Himalayas. This sea probably did not extend much further north, for Tibet was then probably a land area. In this connection it may be mentioned that the age of the Ralam series doubtfully assigned by Heim and Gansser[4] to the basal Cambrian is not precisely known and therefore no correlation with the above-named formations can be suggested at this stage.

We may now consider the correlation of the lower part of the Haimanta system with the Vindhyans. This system includes :—

Fossiliferous slates with *Olenus*	..	1,000 ft. thick.
Slates and quartzites without fossils	..	300–400 ft. thick.

[1] Das-Gupta, H. C. and Vredenburg, E. W. *Jour. As. Soc., Bengal*, N.S. Vol. XIV, p. clxxxv, 1918.

[2] Auden, J. B. *Rec. Geol. Surv. Ind.*, Vol. LXV, p. 536, 1932.

[3] Pilgrim, G. and West, W. D. *Mem. Geol. Surv. Ind.*, Vol. LIII, p. 3, 1928.

[4] Heim, A. and Gansser, A. Central Himalaya. Geological Observations of the Swiss Expedition. *Denkschr. Schweiz. Naturforsch. Gesellsch.*, Bd. LXXIII, Abh. I, p. 202, 1936

The Upper division can be correlated with the *Olenus* zone of the European or American Cambrian and the correlation of the Lower division with the upper part of the Puranas, i.e. the Vindhyans seems most likely. However Burrard, Hayden [1] and Heron observe that

> 'the relations of the Haimantas to the Purana rocks of the Himalayan zone have not yet been worked out and it is not known definitely whether there is a gradual and conformable passage from the one into the other or whether the lower beds of the Haimantas are contemporaneous with the upper strata of the Puranas nor is it possible to say at what period the Himalayan zone of the Puranas first became a land-surface'.

The correlation above suggested, however, appears to possess an air of justifiable speculation. But if admissible the absence of limestones in the Haimantas which are composed mostly of detrital deposits and

> 'the absence of any post-Purana beds among the rocks of the Himalayan zone suggests that the present southern boundary of the Haimanta deposits marks approximately an original limit of deposition and consequently the southern shore of the sea in which the Haimantas were laid down' [2].

the southern shore in fact of the northern Vindhyan sea.

The correlation of the Shillong series of Assam, the Chaung Magyi series of Burma and the Sinian series of China with some part of the Purana system has sometimes been suggested. According to Grabau [3] the Vindhyan strata are undoubtedly referable to the Sinian system. Grabau further considers the Vindhyan system to be entirely of continental origin, which we now know is certainly not the case and I am of opinion that his reference of the whole of the Sinian system to continental deposits will probably be negatived by further evidence. We further know that limestones occur in the Chaung Magyi series in certain parts of the Shan States mapped by Hobson, [4] though no limestones were noticed in the area mapped earlier by La Touche [5] and later by myself. [6] The vast thickness of the Chaung Magyis is probably of marine origin and their correlation with the upper part of the Purana system, i.e., with the Vindhyans instead of with the still older Dharwars as advocated by Holland

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[1] Burrard, S., Hayden, H. H. and Heron, A. M. A sketch of the geology and geography of the Himalaya mountains and Tibet. Pt. IV, p. 335, 1934.

[2] *Ibid.*, pp. 334-335, 1934.

[3] Grabau, A. W. Stratigraphy of China, Palaeozoic supplement, p. 423, 1923-24.

[4] Hobson, G. V. General Report for 1928.

[5] La Touche, T. H. D. *Mem. Geol. Surv. Ind.*, Vol. XXXIX, p. 47, 1913.

[6] Sahni, M. R. General Reports for 1929–1933.

or with the Cuddapahs as suggested by La Touche, seems plausible.

The extension of Sinian strata into Manchuria via the provinces of Shensi and Shantung indicates the eastward extent of the Vindhyan sea. The presence of the Nankou tillite in China shows that while glacial conditions prevailed for a time near the eastern end of the Vindhyan geosyncline, arid conditions held sway far to the west. Locally, however, in the region of Shensi and Honan where red sandstones occur, arid conditions prevailed. The cause of this according to Grabau [1] appears to have been

> 'the height of the bounding ranges of mountains which supplied the sediments and the fact that they intercepted the moisture-bearing winds from the south-east. If this was the case, the belt of easterly winds must have been shifted further northwards at that time, than the position which it now holds'.

We may now attempt to present a more or less connected picture of the Vindhyan panorama. If it is said that much of it is based upon speculative hypothesis, one can only emphasize its inevitability considering the paucity of evidence.

The Vindhyan sediments in the Central Indian region indicate a sea extending from the Vindhyan mountains in the west to as far as Behar in the east and this I propose to call the 'South Vindhyan sea'. The marked overlap of the sediments northwards indicates the approach of land and the Indo-Gangetic alluvial region was probably then a land area. That life had already dawned is shown not only by the presence of such genera as *Fermoria* or *Vindhyanella* but also by the presence of glauconite which, according to various authors is a sure sign of organic existence. During this period arid conditions prevailed.

No rocks which can be correlated with the Vindhyans have been found in Iran and the intervening region as far east as the Salt Range, except the Kalu series of Afghanistan which, according to Hayden [2], recall the Haimantas. One can only suggest the probable occurrence of Vindhyan strata in this area. In this western region then we can only speculate upon the occurrence of marine conditions, but in regard to their continuation eastward along the Himalayan region, through Assam, Burma, the provinces of Shensi, Shantung and Manchuria in China, we are perhaps on a more sure footing, and we may grant the existence of an ancient geosyncline harbouring a northern sea in Vindhyan times. But in the present stage of our knowledge who would attempt to define more precisely

[1] Grabau, A. W. *Loc. cit.*, p. 15, 1923-24.

[2] Hayden, H. H. Geology of Northern Afghanistan. *Mem. Geol. Surv. Ind.*, Vol. XXXIX, Pt. 1, p. 23, 1913.

the boundaries of this northern sea and its probable connections with the South Vindhyan sea of the Central Indian region ?

CAMBRIAN PALAEOGEOGRAPHY.

EXTENSION OF THE CAMBRIAN SEA TO WESTERN ASIA.

Recent work has necessitated far-reaching changes in our conception of the Cambrian palaeogeography of Asia which I would now like to bring to your notice. It was at one time believed that the genus *Redlichia* was confined to eastern Asia and that it did not occur in any other part of the world. It was likewise held that in the Asiatic region, Cambrian strata were confined to eastern and southern Asia. We now know that Cambrian strata as well as the genus *Redhchia* are widely distributed in western Asia having been found at numerous localities in Iran. The statement that 'our ignorance of the existence of any Cambrian beds in Persia (Iran), Asia Minor or north-east Africa prevents any definition of the boundaries of the Pacific province in the region to the west of India'[1] thus needs emendation in important respects. Further evidence might show—indeed there appear to be indications in that direction—that the barrier which is believed to have 'effectually checked the free intermigration of the typical European and Asiatic faunas in this direction (west of India) during Cambrian times' was probably not completely effective, as believed,[2] but permitted slight, very slight, intermingling far in the west.

The extensive occurrence of thick deposits of Middle and Upper Cambrian ages in Iran has been proved within recent years by the geologists of the Anglo-Iranian Oil Company.[3] Fossiliferous Cambrian strata have similarly been recorded from as far west as the shores of the Dead Sea. Indeed this record dates as early as 1910 when Blanckenhorn[4] announced the occurrence of a representative of the genus *Ptychoparia*[5] in that region, but it appears to have been lost sight of. The occurrence of representatives of the Middle Cambrian Hormuz Series on the islands off the pirate coast of Oman and probably also on the Arabian mainland has similarly been proved. These are important discoveries. Of no less significance is the identification of

[1] Reed, F. R. C. *Rec. Geol. Surv. Ind.*, Vol. XL, Pt. 1, p. 15, 1910.

[2] *Ibid.*, p. 15, 1910.

[3] Böckh, H. de, Lees, G. M. and Richardson, F.D.S. Contribution to the Stratigraphy and Tectonics of the Iranian ranges (*in* Gregory, J. W., Structure of Asia, 1929).

[4] Blanckenhorn, M. *Zeitschr. Deutsch. Geol. Gesellsch.*, Bd. LXII, pp. 410–13.

[5] King, W. B. R., remarks that this form which suggests relationship with *Protolenus* may be identical with his *Anomocare campbelli* (*vide Geol. Mag.*, Vol. LX, p. 514, 1923).

Paradoxides from Palestine by Blanckenhorn which even suggests some connection of the Middle Cambrian sea (which we now know extended from the Rocky Mountain region of western America across eastern Asia, the Himalaya, Salt Range and as far west as the Dead Sea) with the European Middle Cambrian Sea, of which *Paradoxides* was the dominant genus. This view was indeed suggested as long ago as 1915 by Dienmann [1] but did not receive sufficient notice. In this connection it may be remarked that according to King [2] the species *Anomocare campbelli* described by him from the Dead Sea region is closely allied to a British form, *Anomocare platycephalum* [3], and probably indicates marine inter-communication. While, therefore, it is true that 'no Mediterranean or ancestral tethys is proved by palaeontological evidence to have then been established, and the dissimilarities between the nearest European fauna and that of Spiti and the Salt Range are therefore marked',[4] the occurrences just mentioned provide additional proof of slight intermingling of the European and Asiatic seas.

We may now consider the evidence for the extension of the (Middle and Upper) Cambrian seas from Spiti to the Salt Range and beyond into Persia and Palestine in greater detail.

THE SALT RANGE CAMBRIAN.

EAST ASIATIC (INDO-CHINESE) AFFINITIES OF THE IRANIAN CAMBRIAN FAUNAS.

The generalized Cambrian succession in the Salt Range is as follows:—

Salt pseudomorph shales	..	Variegated flaggy beds of prevailing purple or green colour.
Magnesian sandstone	..	White or green sandstones, often dolomitic.
Neobolus shales	..	Fossiliferous grey or dark shales.
Purple sandstones	..	Red or purple sandstones.
Salt marl	..	Loose red earth or marl with salt and gypsum.

In an important paper published under the authorship of Böckh, Lees and Richardson [5] it is stated that

> 'the salt plugs of the Persian Gulf are overlain by purple sandstones, sandstones containing salt 'pseudomorphs' and sandy dolomites and shales containing Cambrian trilobites . . . .

[1] Dienmann, W. *Centralbl. fur Min. Geol. und Palaeont.*, Vol. XVI, pp. 23–6, 1915.
[2] King, W. B. R. *Geol. Mag.*, Vol. LX, p. 511, 1923.
[3] Cobbold, E. S. *Quart. Jour. Geol. Soc.*, Vol. LXXVI, pp. 330 1, 1920.
[4] Reed, F. R. C. *Rec. Geol. Surv. Ind.*, Vol. XL, Pt. 1, p. 15, 1910.
[5] *Loc. cit.*, p. 84, 1929.

The sequence given above, showing the purple sandstone immediately overlying the Hormuz salt, corresponds with the salt Range succession '

Pilgrim's assignation of the Hormuz Series to the Jurassic [1] is of course entirely erroneous. The correlation of the Salt Range and Iranian Cambrian successions may therefore be considered established, but this correlation can only be a general one for the description of the Iranian and Salt Range Cambrian trilobites published [2] in recent years does not indicate close affinity between them, though it must be admitted that the number of species recorded is not large. The most noteworthy point therefore is that the Cambrian faunas of Iran are not related to those of Spiti or even the Salt Range but, on the contrary, as we shall presently see, they are closely related to East Asiatic, that is, Chinese and Indo-Chinese faunas. Relationship with Indo-China is especially marked by the presence of the genus *Billingsella*, the Iranian representative of which may be identical with *B. tonkiniana* from Indo-China. Lack of time prevents me from giving a detailed analysis of the faunas of these regions, but reference can be made to the works of Waagen [3], Redlich,[4] Walcott [5] and to the more recent papers by King [6].

AFFINITIES OF THE CENTRAL HIMALAYAN CAMBRIAN FAUNA.

In order to complete the picture I may now consider the Himalayan Cambrian. The evidence so far recorded establishes west American affinities for the Spiti Cambrian faunas. The Spiti species of *Anomocare* and *Ptychoparia* are allied to American forms, while the presence of such genera as *Zacanthoides*, *Oryctocephalus* and *Eocystis* in both regions is noteworthy. It is, however, equally remarkable that the Spiti Cambrian fauna is less affined to the nearer Chinese than to the American faunas, though the occurrence of the

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[1] Drs. Böckh, Lees and Richardson, in their paper just referred to, state that the Iranian Cambrian sequence (Hormuz Series) as given by them does not agree with that given by Pilgrim in his latest Memoir (*Mem. Geol. Surv. Ind.*, Vol. XLVIII, Pt. 2, 1935). Surprisingly enough Pilgrim referred the Hormuz Series to the Jurassic apparently on purely hypothetical evidence, rather than to the Cambrian, and seems to have missed the fossil evidence completely. We may therefore reasonably accept the Hormuz succession as given by the first named authors rather than Pilgrim's.

[2] King, W. B. R. *Pal. Ind.*, New Ser., Vol. XXII, Mem. No. 5, 1937.

[3] Waagen, W. *Pal. Ind.*, Ser. XIII, Vol. I, 1887; *ibid.*, Vol. IV, 1891.

[4] Redlich, K. *Pal. Ind.*, N.S., Vol. I, Mem. No. 1, 1901.

[5] Walcott, C. D. *Proc. Washington Acad. Sc.*, Vol. VII, pp. 251–256, 1905.

[6] King, W. B. R. *Rec. Geol. Surv. Ind.*, Vol. LXXV, Professional paper No. 9, p. 40.

Chinese genus *Shantungia* in Spiti (apart from *Redlichia*) shows that free communication existed between these regions. The presence of many cosmopolitan genera like *Agnostus*, *Microdiscus*, *Anomocare* and *Ptychoparia* further emphasizes this connection though less importance is usually attached to such types. The occurrence of *Olenus* at Spiti further indicates a northern connection of the Himalayan Cambrian sea with the European sea, but with that we are not here concerned.

FAUNAL ANOMALIES AND THEIR PROBABLE EXPLANATION.

One fact of great importance which thus emerges is the marked divergence of the M. Cambrian faunas of Iran, the Salt Range and Spiti. The affinities of the Iranian Cambrian faunas with the far Chinese and Indo-Chinese to the exclusion of those of the Salt Range and Spiti raise some important questions concerning the routes of migration of these faunas and their inter-relationship. How are we to reconcile the diverging affinities of the Cambrian faunas of these regions ? Does this divergence postulate the occurrence of physical barriers or is it capable of some other explanation ? Let us for a moment examine the position.

This divergence suggests at first sight that the route of migration of the M. Cambrian faunas to Iran did not lie across the Salt Range region. Two alternatives are possible. Firstly it may be suggested that there was an independent connection between the Iranian and Chinese regions. There is however no evidence of this. Therefore the solution probably lies in the second alternative that so far as the M. Cambrian is concerned, the apparent discrepancies between the Iranian, Spiti and Salt Range faunas are probably due to differences in horizon within the Cambrian series, rather than to absence of direct communication between these regions.

This view is also suggested by recent work [1], as a result of which it has been established that the following succession of faunas occurs in Iran :- -

4. *Saukia* fauna	..	High U. Cambrian.
3. *Chuangia* fauna	..	Low U. Cambrian.
2. *Irania* fauna	..	Highest M. Cambrian.
1. *Redlichia* fauna	..	Basal M. Cambrian.

According to this view the Salt Range Cambrian corresponds approximately to horizon I. of M. Cambrian age where also the *Redlichia* horizon of Spiti belongs, while still higher beds in the Himalayan Cambrian probably fit into the gap between the *Redlichia* and *Irania* faunas of Iran.

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[1] King, W. B. R. *Pal. Ind.*, New Ser., Vol. XXII, Mem. No. 5, 1937.

No Upper Cambrian strata have been found in the Salt Range. It may thus be maintained that in Upper Cambrian times the sea retreated from the Salt Range while it still persisted in Iran where the *Saukia* and *Chuangia* faunas then flourished, and probably also in the Central Himalaya where *Olenus* occurs and shows a northern connection with the Upper Cambrian *Olenus* sea of Europe. But if a post Middle Cambrian barrier (in the region of the Salt Range) separated the sea in Iran from its eastern continuation, we cannot expect to find the Iranian Upper Cambrian fauna affined to faunas further east of the Salt Range unless the barrier was of short duration. Such affinities, however, do exist and suggest communication via the Himalayan region.

The discoveries of Cambrian trilobites in Kashmir by the Yale North India expedition and by Wadia [1] appear to lead in a remarkable manner to this conclusion, for Cowper Reed has recently described the Upper Cambrian genus *Chuangia* from Kashmir [2]. It defines the basal Upper Cambrian horizon in Iran. This genus is thus common to Iran, Kashmir and Indo-China, and therefore the Kashmir region forms a definite link between Iran on the one hand and Indo-China on the other. The same is true of the Middle Cambrian. From Hundwara (Yale expedition collection) Kobayashi[3] has described a species of *Agnostus* which he compares with *A. rakurdenses* from Chosen in China. The form described by Reed [4] from Spiti as *Ptychoparia memor* has also been found in Kashmir though referred by Kobayashi to *Anomocarella*, and is compared with *An. megalurus* Dames, from Tonkin. More important still, the characteristic Indo-Chinese genus *Tonkinella* is now recorded from Kashmir [5] in the species *T. breviceps* Kobayashi. The occurrence of species of *Anomocare* and *Conocoryphe* in Kashmir which are closely allied to the Indo-Chinese species is likewise of great interest and emphasizes marine connection between these regions. The genus *Redlichia* has, however, not been found in Kashmir.

EASTERN ASIA.

East and south-east of the Central Himalayan region there is a big gap for no Cambrian strata are known either in Assam, in the Arakan Yomas or even in Burma proper.

[1] Wadia, D. N. The Cambrian-Trias sequence of North-Western Kashmir. *Rec. Geol. Surv. Ind.*, Vol. LXVIII, Pt. 2, pp. 137–142, 1935.

[2] Reed, F. R. C. *Loc. cit.*, p. 18, 1934.

[3] Kobayashi, T. *Amer. Journ. Sc.*, Ser. 5, Vol. XXVII, pp. 295–302, 1934.

[4] Reed, F. R. C. *Pal. Ind.*, Ser. XV, Vol. VII, Mem. No. 1, 1910.

[5] Kobayashi, T. *Loc. cit.*, Pt. 1, pp. 1–6. 1934. See also Reed, *Pal. Ind*, N.S., Vol. XXI, Mem. No. 2, p. 9, 1934.

The eastward extension of the Cambrian sea is, however, proved by the occurrence of Cambrian fossils in Yunnan [1] (genus *Mesonachis*) Indo-China [2] (genera *Coosia*, *Chuangia*, *Billingsella*, etc.) and China. It was thought that the Chinese M. Cambrian possessed a marked local impress [3] suggested by the genera *Damesella*, *Drepanura* and *Blackwelderia*. In a paper by King [4] now in the press the probable occurrence of *Blackwelderia* in the Salt Range is noticed, and this is not without significance.

The discovery of *Chuangia* in Kashmir indicates clearly that the westward migration of Indo-Chinese forms lay along the Himalayan region, that discoveries of new horizons must be expected and that the supposed discrepancies between the Cambrian faunas of neighbouring regions (when those of distant areas are related) are probably due to slight differences in horizon of these faunas. Likewise the identification of *Blackwelderia* in the Salt Range suggests that much more remains to be done before we can explain the divergences of faunas by reasons other than by the absence of detailed information.

RECENT EVIDENCE BEARING ON CAMBRIAN PALAEOGEOGRAPHY.

We have seen that there is no certain record of the Lower Cambrian in Iran, unless the rocks at Kuh-i-banan and Kuh-i-dinar are so regarded, and that in all probability this horizon is missing also in the Salt Range. Further east, too, no Lower Cambrian strata are met with till we reach the Indo-Chinese region. We may therefore conclude, on the evidence at present available, that the Lower Cambrian in southern and western Asia was dominantly a continental period. Grabau, as also some of the earlier authors, however, regard the various *Redlichia* horizons as Lower Cambrian and in palaeogeographic maps the Lower Cambrian sea is shown to extend from China to as far as the Salt Range. Since *Redlichia* has now also been found in Iran the Lower Cambrian sea would according to these views extend into western Asia. More recent studies, however, regard the *Redlichia* horizons as basal Middle Cambrian, or possibly topmost Lower Cambrian. But the range of this genus may well be much greater than we suspect.

The Middle Cambrian was a period of widespread marine transgression and the Middle Cambrian sea extended from north-west America to western Asia, as far perhaps as the Dead Sea.

[1] Mansuy, H. *Mem. Serv. Geol. Indochine*, Vol. I, fasc. 2, 1912.
[2] *Ibid.*, Vol. IV, fasc. 2, 1915.
[3] Grabau, A. W. Stratigraphy of China, p. 28, 1923-24.
[4] King, W. B. R. *Rec. Geol. Surv. Ind.*, Vol. LXXV, Professional paper No. 9, 1940.

With the exception of the Salt Range area, the evidence of the Upper Cambrian faunas shows the perpetuation of Middle Cambrian marine conditions into Upper Cambrian times. But the close affinities of the west and east Asiatic faunas (Iran and Indo-China respectively) are strongly suggestive of a continuous passage, even though there was a temporary retreat of the Upper Cambrian sea from the Salt Range area.

As will appear presently, at the close of the Upper Cambrian period the sea retreated entirely from the region west of the Central Himalayan area.

ORDOVICIAN.

RETREAT OF SEA FROM WESTERN ASIA.

Towards the close of the Cambrian period a great change came over the western Asiatic region. The sea which, at least during the Middle and late Upper Cambrian times girdled the earth from the Mediterranean region to the western shores of North America receded from the region of the Dead Sea, Iran and the Salt Range, for no Ordovician or Silurian strata have so far been found in Iran, Afghanistan, Beluchistan or the western Himalayas. These areas thus became dry land. Indeed the whole of this region remained a land area till the Middle Devonian. In M. Devonian times a world-wide transgression gave rise to marine conditions once again and the seas flowed westwards over the site of the Cambrian geosyncline and broke through to mingle with the Middle Devonian sea of northern Europe.

THE PUZZLE OF THE HIMALAYAN AND SHAN ORDOVICIAN FAUNAS.

One of the most important and intriguing problems of the Ordovician of southern Asia is the anomalous position of the Himalayan and Burmese Ordovician faunas. Considerable emphasis is invariably laid on the fact that while the Burmese faunas are more closely allied to those of Europe, the Himalayan forms show American affinities.

Thus according to analyses by La Touche and Cowper Reed as many as sixty-six per cent of the Northern Shan State Ordovician species possess European affinities (10 being identical to the two regions), while only about twenty-seven per cent are related to American forms. On the other hand, as many as forty-two per cent of the Himalayan Ordovician fossils are believed to possess American affinities, though none of the species are common to these areas. The contrast between the Himalayan and Burmese faunas is equally well marked, for only 11 out of 124 Himalayan species are allied to Shan States forms and only three forms are identical in the two regions. The composition of the Himalayan and Shan faunas is also totally different, for

while Cystideans and Trilobites predominate in the Shan faunas, Mollusca, Brachiopods and Corals form the leading elements in the Himalayan fauna. We are thus once again face to face with the same problem that we meet in the case of the Cambrian faunas of Iran, the Salt Range, Himalayas and Indo-China. The Shan States Ordovician faunas lie along the route of the westward invasion of American faunas. How was it, then, that this invasion failed to leave an impress upon the Shan faunas while it gave the far Himalayan faunas their distinctive American stamp? The absence of American types, still further east or north-east, that is, in Burma and China, along the probable route of migration is no less a puzzle. And if it is sought to explain this anomaly by postulating an invasion from the south, via the region of the present Indian Ocean, then the absence of American species in the neighbouring regions still remains unexplained.

The American affinities of the Himalayan faunas when those of the Shan faunas are European as well as the striking contrast in their composition, have suggested the presence of barriers between the two regions. However, to any one familiar with the state of preservation of the Himalayan Ordovician fossils it seems obvious that too much emphasis has been laid upon their apparent American affinities, and sufficient cognizance has not been taken of the fact that we are probably dealing with varying horizons. Certain authors even believe that this apparent similarity is due to parallel evolution. Recent fossil discoveries in the Southern Shan States, accounts of which have been published by Reed,[1] seem to support the former hypothesis.

An analysis of the Southern Shan States faunas shows that most of the forms are new. And while the proportion of forms related to European species is comparatively large the fauna also possesses decided American affinities, though no distinctive American species occur. These fresh discoveries appear to indicate that while the European element in the Shan faunas is predominant it is not such in every case, the Southern Shan States, for example, as so completely mask the American element. One may therefore venture to suggest that we are not dealing with identical horizons and that the exact equivalents of the Himalayan Ordovician still remain to be discovered in the eastern region. Indeed the available evidence seems indirectly to point this way, for in the Himalayas strata of Upper Ordovician age are absent and only Middle Ordovician horizons are known. In the Northern Shan States, according to Reed,[2] only the Lower Ordovician is represented or rather the Lower Ordovician is definitely known, but higher horizons (stage C of the Baltic region) are probably present. The Nyawngbaw limestone of the

[1] Reed, F. R. C. *Pal. Ind.*, New Ser., Vol. XXI, Mem. No. 3, 1936.
[2] *Ibid.* *Pal. Ind.*, New Ser., Vol. II, Mem. No. 3, pp. 83–86.

Northern Shan States is of course of Upper Ordovician age and Schuchert concurs in this view on account of the occurrence of *Camarocrinus asiaticus* in it. In the Southern Shan States the Ordovician is represented by the Middle division, possibly also the Upper.

Another point to consider is that while there is an extensive development of the Orthoceras limestone in the Southern Shan States, these limestones are hardly known in the Northern Shan States. These limestones are correlated with the Orthoceras limestones of Yunnan and the Nechiasan formation of Hupeh which are of M. Ordovician age as are also the Orthoceras limestones of S. Manchuria, Karakorum, Sweden and the Vaginatenkalk of the Baltic region.

EASTERN ASIA.

Rocks of Middle Ordovician age are known from western Yunnan, but this formation appears to be entirely absent from eastern Yunnan. The western Yunnan[1] faunas however differ remarkably from those of the Shan States, for whereas graptolite horizons are extensively developed in the Yunnan Ordovician, these are not represented in the Naungkangyis, though a few species are common to the two regions. The horizon represented in Yunnan is the zone of *Didymograptus murchisoni* or Upper Llandelian. A still higher horizon, equivalent of the Nyawngbaw Limestone of the Shan States is represented in the Shih-tien beds in which *Camarocrinus asiaticus* occurs.

The Ordovician of Indo-China is of great interest, for although it is related to that of western Yunnan, it contains the species *Calymene douvillei* Mans. and *Rafinesquina umbrella* Salter of which the former is closely related to the Himalayan *C. nivalis* Salter while the latter actually occurs in the Himalayan Ordovician beds. In Annam the *Asaphus* sandstones represent the Ordovician, and, like the Tonkin beds, are of late Ordovician age. They contain such characteristic forms as *Orthis budleighensis* Dav. and *Strophomena expansa* Sow. of the north European seas.

Important changes took place in eastern Asia during late Upper Ordovician times. There are no uppermost Ordovician fossils found in the whole of the Chinese region which became a land area after the close of the Middle or early Upper Ordovician times. Lower and Middle Ordovician faunas are known from various parts of China and while the boreal facies prevails in the north, European forms are dominant in central and south-western China, as in Upper Burma.

[1] Reed, F. R. C. *Pal. Ind.*, New Ser., Vol. V, Mem. No. 3.

The absence of the highest Ordovician strata in eastern and southern Asia is evidence of a break of considerable magnitude and of the shrinking of the Ordovician seas of these regions. During the Middle Ordovician, however, marine waters spread over parts of northern as well as southern China, Yunnan, Upper Burma (Shan hinterland) and sweeping south of the Tibetan plateau extended at least as far as the Central Himalayan region. where the Shiala Series [1] and their equivalents were deposited. West of this, the great Cambrian geosyncline which extended along the western Himalayas and the Salt Range and Iran had already shrunk out of existence and western Asia had become a land area.

WAS TIBET AN ISLAND?

We have seen that the Central Himalayan Middle Ordovician faunas possess an American impress, though I believe that this aspect of their affinities is often exaggerated. We have also laid emphasis on the fact that the probable route followed by these faunas is unknown and is still one of the puzzles of Asiatic geology. The palaeontological evidence so far available suggests only a single pathway for the eastward migration of the Ordovician faunas, namely, via the main Himalayan geosyncline south of the Tibetan plateau region, for there is no record so far of Ordovician strata north of this area. The American geologist Bailey Willis [2] in discussing the distribution of land and sea in central and eastern Asia, however, comes to the conclusion based, presumably, upon tectonic evidence that west of the Tibetan region the great Himalayan tethys forked into two branches: the main or Southern Tethys sweeping the southern shores of the Tibetan plateau and a lesser or Northern Tethys flanking this region on the north so that the Tibetan region stood as an island in this sea. This is designated *Isle Tibet* by Bailey Willis. The Southern Tethys, of course, corresponds to the universally accepted Himalayan Tethys founded upon palaeontological and stratigraphic evidence.

It is as yet too early to suggest whether the isolated character of the Spiti Middle Ordovician fauna with its American phase can be explained upon the basis of this northern ocean highway, for geologists have accepted only the single, Southern Tethys. But the tectonic evidence upon which the Northern Tethys is apparently based is of considerable interest.

In this connection, however, the remarks made by Burrard, Hayden and Heron [3] may be quoted. They say, 'having regard

[1] Heim, A. and Gansser, A. *Denkschr. Schweiz. Naturforsch. Gesellsch.*, Bd. LXXIII, Abh. I, p. 203, 1936.

[2] Bailey Willis. Research in China. Systematic Geology, Vol. II, pp. 35–69, 1907.

[3] *Loc. cit.*, p. 338, 1934.

to our ignorance of the geology of the greater part of Tibet, we can offer no direct observations bearing on this question; but if we turn to north-eastern Ladakh, we find Palaeozoic rocks exposed in the neighbourhood of Changchenmo and Pangong Lake, and if, as appears to be the case, the trend of these beds is the same as that of the rest of the Tibetan zone in Kashmir, Spiti and Kumaon, we should expect to find them well to the north of the head-waters of the Indus and Brahmaputra in western and central Tibet. We are, therefore, inclined to believe that Palaeozoic beds do occur in the great lake-basin of central Tibet. They may possibly be hidden by the younger (Mesozoic) deposits . . . but it may reasonably be expected that they will be found to crop out here and there, and thus prove that the sea in which the Dravidian (Palaeozoic) rocks of the Tibetan zone were laid down was not, as has been assumed, merely a strait connecting eastern and western Asia, but extended northwards over the greater part of Tibet.'

INVASION OF THE EUROPEAN ORDOVICIAN FAUNA INTO SOUTHERN ASIA.

Very little indeed is known concerning the route followed by the European Ordovician faunas during the course of their invasion of the south Asiatic region. But it is a remarkable fact, one that demonstrates the accuracy and fineness of palaeontological correlation that some at least of the graptolite zones of the British Ordovician (*Didymograptus murchisoni*), the fine development of the Orthoceras Limestone of Sweden and other Baltic lands, and such characteristic Caradocian species of western Europe as *Orthis calligramma, Orthis vespertilio, Dalmanella testudineria, Plectambonites sericea, Strophomena expansa* have also been recorded either in the Ordovician strata of the Shan hinterland or Yunnan or southern China. We have unfortunately no record of Ordovician strata north or west of the central Himalayan region till we meet the Ordovician strata of western Europe already referred to. We can therefore but speculate on the marine connection between the Indo-Burmese region and Europe, but it probably followed a north-westerly course from the central Himalayas to the present Baltic region. In this connection I must refer to the find of graptolites [1] (genus ?*Diplograptus*) made by Harrison and Tait, of the Anglo-Iranian Oil Company, "at Furgun, 50 miles west of Bandar Abbas, close to the front of the zone of Nappes". This find if confirmed possesses considerable significance where the migration of Ordovician faunas is concerned.

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[1] Böckh, H. de, Lees, G. M. and Richardson, F. D. S. *Op. cit.*, footnote, p. 69, 1929.

SILURIAN.

LOWER SILURIAN TRANSGRESSION IN THE INDO-BURMESE AND CHINESE REGIONS.

The close of the Ordovician or early Silurian marks a period of profound marine transgression over India, Burma, Indo-China, Yunnan as well as central and southern China. Indeed this transgression which appears to have reached its zenith in Wenlock times, affected the European continent as well as north America: and 'one common Silurian ocean seems to have spread round the northern hemisphere'.[1] But with the extra-Asiatic aspects of this problem we are not here concerned.

No Silurian strata have been found in the Asiatic countries west of the Himalayas and therefore the extension of the Himalayan Tethys into Afghanistan, Beluchistan and Iran is uncertain. The first strata of this age that we meet in that direction are in the Mediterranean region. It may be mentioned that the same remarks were applicable to the Cambrian (except for its occurrence in the Salt Range) till the discovery in Iran of extensive deposits of Middle and Upper Cambrian ages.

THE HIMALAYAN SILURIAN.

Our knowledge of the Silurian strata of the Himalayan region has not increased during recent years even though considerable exploratory work has been carried out by Wadia, Arnold Heim, West, Auden and others. The old collections upon a study of which the main conclusions concerning the relationship of the Himalayan Silurian faunas were based still remain practically unsupplemented by fresh discoveries, which leaves, it need hardly be said, a big lacuna in Himalayan palaeontology.

The Silurian rocks of the Himalayas belong entirely to the Lower Silurian division, being represented by the Llandovery and possibly also by the Wenlock. The presumed Upper Silurian age of some of the Himalayan beds appears to be uncertain. There is here as indeed everywhere in Asia a profound break in the marine depositional history so that the Middle Silurian is either entirely absent or is represented only by terrestrial deposits, as in parts of America, where this division constitutes the well-known Salina formation.

The Himalayan Lower Silurian fauna presents interesting affinities which throw much light on the palaeogeographic relationships of that period. This fauna is composed of (*a*) species which are confined to the Himalayas, (*b*) species that are either identical with or allied to north European forms and (*c*) an admixture of species allied to American forms.

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[1] Reed, F. R. C. *Rec. Geol. Surv. Ind.*, XL, p. 26, 1910.

La Touche has attempted a percentage analysis of this fauna and comes to the conclusion that the Himalayan Silurian contains an almost equal proportion of American and north European forms, fifty-one and forty-nine per cent respectively, to be more exact.[1] It will be remembered that in the case of the Himalayan Ordovician this proportion according to the same authority was 42 per cent to 25 per cent, which means a predominating American element. In this connection it may be pertinent to remark that while in the case of the Ordovician fauna the analysis was based upon 124 species, only 35 species were available for the Silurian. We cannot sufficiently emphasize the fallacy of such comparisons and analyses where the collections are inadequate, the fossils far from well preserved and where in consequence it is impossible to adjudicate the relative degree of their affinities. That this is not a hasty verdict may be shown by the fact that Reed, who published the studies on these Himalayan fossils, assigns predominantly north European affinities to them. The large number of corals in the Himalayan Silurian in comparison with the Burmese Silurian, however, show distinct American affinities and among them one form appears almost identical with *Favosites niagarensis* Hall, from the American Silurian.

The Silurian formation in Kashmir must be assigned to the Lower division,[2] namely, Llandovery, on account of the presence of such forms as *Triplecia insularis* Eichw., *Orthis sowerbyana*, *Lindstroemia* cf. *bina* (Lonsd.). Species of *Acidaspis* and *Illaenus* likewise possess Llandovery affinities. It is, however, probable that the presence of *Conchidium knighti* at a different locality indicates the Aymestry Limestone, a horizon high up in the Salopian.

However, the main upshot of this discussion with which we are primarily concerned here is that the occurrence of both American and north European forms postulates marine connection of the Himalayan geosyncline with both these regions during Lower Silurian times. The probable route followed by these faunas will be considered presently.

AFFINITIES OF THE SHAN SILURIAN.

PREDOMINANT SHELLY FACIES OF THE NORTHERN SHAN STATES.

We have already drawn attention to the dominantly North European character of the Shan Ordovician fauna. It is perhaps,

[1] La Touche, T. H. D. *Mem. Geol. Surv. Ind.*, Vol. XXXIX, p. 161, 1913.

[2] Reed, F. R. C. *Rec. Geol. Surv. Ind.*, Vol. XLII, Pt. 1, pp. 16–33, 1912.

therefore, not surprising that the Shan Silurian faunas are also strikingly North European in character which is expressed by such species as *Halysites catenularia* Linn., var. *kanaurensis* Reed. *Orthis* (*Dalmanella*) *basalis* Dalm., var. *muthensis*, *O. calligramma* Dalm., *Leptaena rhomboidalis* Wilck., *Stropheodonta compressa* (Sow.), *Pentamerus oblongus* Sow., *Orthoceras* cf. *annulatum* Dav., *Encrinurus* cf. *punctatus* Brunnick. The only South European type is *Mimulus*. Most of these are Wenlock species and in the Northern Shan States this shelly facies predominates. This conclusion is borne out not only by the earlier work of La Touche but also by the studies based upon recent collections made by Coggin Brown, Sondhi and myself. Concerning the Zebingyi beds which are usually placed in the Silurian more will be said later.

PREDOMINANT GRAPTOLITE FACIES OF THE SOUTHERN SHAN STATES.

To Sondhi goes the credit of discovering the first graptolites in the Southern Shan States. In this region the graptolite facies is very much more widespread than the shelly facies, the reverse in fact of the position in the Northern Shan States. The palaeontological accounts published by Cowper Reed first in 1932[1] and again in more exhaustive detail in 1936[2] show clearly that the Valentian stage is well developed while the Wenlock stage is subordinate. In both horizons, however, the North European affinities are predominant. In the Namshin stage for example out of 45 species as many as 27 are identical with European Wenlock forms. Slight discrepancies have, however, been noticed, but we cannot take account of them in the brief space of this address. It is also worthy of remark that the Trilobite beds of Panghsa-pye (Northern Shan States) have not been found in the Southern Shan States.

RELATIONSHIP BETWEEN THE SHAN AND HIMALAYAN SILURIAN.

The important point to consider now is the relationship between the Himalayan and Burmese Silurian faunas. We have seen that the Ordovician faunas of these regions present a marked contrast, though how far this contrast is emphasized by imperfections of the geological record or indifferent state of preservation it is not easy to say. However that may be, the Silurian faunas present an even greater contrast than the Ordovician for the graptolite facies which is so well developed in parts of Burma as well as Eastern Asia is entirely absent in the Himalayas and no graptolites have so far been found in any part of the Himalaya mountains.

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1 Reed, F. R. C. *Rec. Geol. Surv. Ind.*, Vol. LXVI, Part 2, 1932.

2 *Ibid.* *Pal. Ind.*, New Ser., Vol. XXI, Mem. No. 3, 1936.

As a result of this apparent faunal divergence La Touche emphasizes the presence of an 'unsurmountable' barrier between the Himalayan and Burmese regions from the Ordovician till the close of Silurian times. When we consider the very limited thickness and the usually soft shaly character of the graptolite beds, it becomes difficult to assert how far this lacuna is the result of difference in facies or actual absence of record or of their not having been found so far in the Himalayas. Moreover, if we do not take into account the exclusively Himalayan species such as *Propora himalaica*, *Caliostylus dravidiana*, *Favosites spitiensis*, *Orthis spitiensis*, etc., practically 25 per cent of the remaining species are either identical with or allied to North European forms found in Burma, and at least one species, *Encrinurus punctatus*, is closely allied to an exclusively Burmese species. Although it is true that almost all of these are cosmopolitan forms, yet their number is comparatively so large when the entire known fauna is considered (35 species in all) that we seem to be on fairly safe ground in postulating a freer marine connection than La Touche's remarks and analyses would have us believe, between the Himalayan and Burmese regions. This was so at least during Wenlock times, that is to say following the period (Lower Valentian) when the graptolite beds of the Southern Shan States were being deposited.

SILURIAN OF EASTERN ASIA.

The continuation of the Lower Silurian sea into Western Yunnan and Central China is proved by the presence of fossils of North European type and other forms which are profusely represented in the Shan Silurian. 'This fauna entered the Chinese basin through the Himalayan geosyncline, passing north along the West Yunnan-Szechuan geosyncline and spread in the Tsingling geosyncline as far east as the Nanning hills region of to-day. It was represented partly by a trilobite and brachiopod facies, partly by a pelecypod facies and in certain sections where deltas of mud were forming near the shore, it is represented in the graptolite facies [1].'

This last fact assumes importance when we remember that the graptolite facies is considerably developed in the Southern Shan States, which implies that the Shan Lower Silurian sea did not extend much further south of the Southern Shan States. This is of course apparent from other geological considerations.

RETREAT OF THE LOWER SILURIAN SEA FROM ASIA: UPPER SILURIAN TRANSGRESSION.

The end of the Lower Silurian marks a period of profound negative movement of the sea in Asia as well as outside the

[1] Grabau, A. W. Stratigraphy of China, Part I, p. 35, 1923-24.

Asiatic continent. The seas withdrew along the entire length of the Himalayan region, from Burma, Indo-China as well as from the whole of the Chinese basin. No Middle Silurian marine deposits are known from any of these lands. Northern China, it may be remarked, was already a land area even in Lower Silurian times and remained such till the advent of the Middle Devonian.

The Indo-Burmese region as almost the whole of Western Asia appears to have remained a land area during the Upper Silurian as well. The recent surveys by Coggin Brown and Sondhi in the Southern Shan States and by myself in the Northern and Southern Shan States have not revealed any strata of undoubted Upper Silurian age in Burma.

While the whole of Asia appears to have remained a land area from the close of the Lower Silurian to the end of the Upper Silurian, a minor transgression with an American type of fauna invaded parts of Yunnan, Tonkin and the neighbouring region to the east of it in Upper Silurian times. This invasion was in all probability from some southern source, for no Upper Silurian rocks are found to the east of these regions which would connect the American Upper Silurian Sea with the South Chinese basin across Eastern Asia. It is only to be expected that this fauna coming after a hiatus of great magnitude represented by the lapse of the Middle Silurian, was totally different to the Lower Silurian fauna of these regions. This striking discord is most significant, for while the Lower Silurian fauna is North European, this Upper Silurian fauna bears an American stamp. There appears, therefore, to have been no manner of connection between the North European and South Asiatic seas in Upper Silurian times. With the Lower Silurian seas, however, the case as we have already seen was entirely different, for they were in close intercommunication. But what was the route followed by these invading North European Lower Silurian faunas into Asia? The southern end of this route appears to be quite clear, for we have followed the distribution of the European faunas through the Himalayan region across, Burma, Indo-China into the main Chinese basin. It is when we attempt to trace this pathway across Central Asia that difficulties arise. The earlier work suggests that the route lay across Russian Turkestan and Timan where Silurian faunas have been discovered. I am unable at this stage to say whether more recent work of the Russian geologists (usually in Russian) has been able to define more precisely this connecting link between Asia and Europe.

DEVONIAN.

LOWER DEVONIAN (ZEBINGYI BEDS). A MEDITERRANEAN FAUNA IN SOUTHERN ASIA.

The commencement of the Devonian witnesses one of the most interesting episodes in the geology of Southern Asia,

namely, the sudden influx of a fauna which bears no relation to the faunas of immediately surrounding regions, but is a prototype of the far Mediterranean Lower Devonian fauna. It is the fauna which is represented in the Bohemian region by the well-known Hercynian facies.

This influx is the more remarkable, for whether in the Himalayas or the Shan hinterland the earlier strata betray hardly any suspicion of Bohemian or South European elements. Some of the exceptions, to which attention has already been drawn, are the presence of the genus *Aristocystis* (*A. dagon*) in the Ordovician and of *Mimulus* (*M. aunglokensis*) and a species of *Phacops* in the Silurian strata of the Northern Shan States. The percolation of these South European types in the earlier Ordovician and Silurian times probably indicates only an indirect connection with that region, for we have seen that direct connection during this period was with the North European seas.

At all events this episode is but an isolated phenomenon, for apart from the Shan region this fauna appears to have made but little headway. Its isolation becomes the more striking when we realize that we have but few intervening connecting links between Southern Europe and Asia so that the probable pathway of migration of this fauna still remains a matter of speculation.

AGE OF THE ZEBINGYI FAUNA.

The most interesting and puzzling fact about this fauna is, however, not its isolation and Hercynian affinities, but its composition, which makes the question of its exact age indeed a perplexing problem. These beds contain closely associated with each other forms which we are accustomed to regard as exclusively Devonian (*Tentaculites elegans* Barrande and the genus *Styliolina*) or exclusively Silurian (*Monograptids*). What then is the age of these beds, Silurian or Devonian? The author as a result of field examination in 1929 came to the conclusion that in their stratigraphical relations the Zebingyi beds are more closely associated with the overlying Plateau Limestone than with the underlying Ordovician beds, and in this respect agreed with the observation made earlier by La Touche. La Touche [1], like Grabau [2], inclines to a definitely Silurian age on account of the graptolites; Schuchert [3] is definite about their Lower Devonian age in spite of the graptolites. While Reed [4] although he includes them under the Silurian section appears to

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[1] La Touche, T. H. D. *Mem. Geol. Surv. Ind.*, Vol. XXXIX, p. 178, 1913.

[2] Grabau, A. W. Stratigraphy of China, Pt. I, p. 121, 1923-24.

[3] Schuchert, C. *Amer. Journ. Science*, Ser. 4, Vol. XXV, p. 262, 1908.

[4] Reed, F. R. C. *Rec. Geol. Surv. Ind.*, Vol. XL, Pt. 1, pp. 26-27, 1910.

incline to the Devonian view and points out that Devonian graptolites have been described by Ruedmann.[1] In my opinion the fauna as a whole indicates the Lower Devonian. Through the maze of this conflicting evidence it seems impossible to sift and assign a precise age to these beds, but if we weigh the evidence upon its merits and forget our preconceived bias that graptolites were annihilated at the close of the Silurian, I think the Zebingyi beds should be assigned to the Lower Devonian. The conformable passage of the Zebingyi beds into the overlying Plateau Limestone likewise supports this conclusion, though there cannot be any finality about such evidence.

PROBABLE PATHWAY OF MIGRATION

Other areas in Asia where the South European type of faunas have been found are in the neighbourhood of Baroghill pass [2] in Chitral, in Turkestan [3], in the Urals [4] and in the region to the north of Tibet.[5] Now although Grabau remarks upon the 'very close connection which exists between these central Asiatic faunas and those of the corresponding age in the Urals', yet there appears to be very little in common between them and the Lower Devonian Zebingyi fauna of the Shan States.

What then was the sea-route of this (Zebingyi) fauna during its long journey to Asia? Indeed was this fauna one of European origin at all, which had migrated to Asia or was it, as the presence of Graptolites might indicate a fauna established in some nearby Asiatic region, which had in course migrated westwards into the south European basin?

There appears to have been but little connection with the Urals, for with the exception of the lamellibranch genus *Vlasta*, there is not much in common between these Hercynian faunas of the Urals and the Shan States. There is further no evidence whatever in the Himalaya mountains of a Hercynian fauna, even if we are to accept the Muth Quartzites as the probable equivalent of the Zebingyi beds. But since there is no trace of the Lower Devonian in Iran which would offer a direct connection of the Shan with the Mediterranean region, one can only accept a connection via the Urals already vaguely implied by the genus *Vlasta* which occurs in Bohemia, the Urals, Zebingyi beds and even in America. The genus *Vlasta* it must be stated is usually

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[1] Ruedmann. New York State Museum, Mem. No. 7, 1904.

[2] Reed, F. R. C. *Rec. Geol. Surv. Ind.*, Vol. XLI, Pt. 2, pp. 86-87, 1911.

[3] Muschketow, D. *Neues Jahrb. für Min. Geol. und Paleontol.*, Bd. 1, pp. 25–42, 1914 and Weber, *Bull. Com. Geol. St. Petersbourg*, Vol. XXIX, pp. 603–695, 1910.

[4] Tschernyschew, Th. *Mem. Com. Geol.*, Vol. IV, 3, 1893.

[5] Hayden, H. H. *Mem. Geol. Surv. Ind.*, Vol. XXXVI, p. 34, 1912.

assigned to the Silurian. What is the exact value of this evidence I shall leave to your taste and inclination.

In this connection, in my opinion, much significance attaches to the occurrence of the Hercynian fauna north of Tibet, meagre though it is. If the Zebingyi fauna is an immigrant from Central Asia or further afield from Europe, it is not improbable that it came via the region north of Tibet and found its way into the Shan region via the eastern margins of Tibet and the Chinese provinces north of the Shan plateau. But future work alone can show how far this surmise is correct.

MIDDLE DEVONIAN.

The marine transgression which took place in Middle Devonian times has few parallels in the geology of Asia. This resulted not only in the intermingling of the Asiatic fauna of different regions, but also as emphasized by Reed in the breaking down of barriers of Asiatic and European life provinces which gave rise to similar faunas in widely separated regions. Attention has already been drawn in this connection to the identical character of the Eifelian faunas of the Shan States and Northern Europe.

On the present occasion I can hardly hope to review in detail the Devonian faunas of Asia, for it is a subject upon which a great deal has been written.[1] I can, therefore, do little more than put forward before you the salient aspects of this problem.

Very little has been added to our knowledge of the M. Devonian faunas of Western Asia in recent years. Mention may be made of a paper by Cowper Reed[2] entitled 'Devonian fossils from Chitral, Persia, Afganistan and the Himalaya'. The same remark applies to the Himalayan region, for no Middle Devonian fossils have been recorded from any part of the Himalaya in recent years. Of the few records mention may be made of the Middle Devonian occurrences in Byans, Kanaur and Upper Spiti described by Reed in the paper just referred to. In Burma too until recently the only known Middle Devonian fauna was the classical Padaukpin (Northern Shan States) fauna discovered by La Touche over thirty years ago and described by Reed in 1908. The only addition after the lapse of three decades is the find I was fortunate enough to make a few years ago of highly fossiliferous Middle Devonian beds near the village of Meso in the Southern Shan States. This constitutes the only record of Devonian fossils in the Southern area. It is unnecessary to give a complete list of the fossils found here, but among others the

[1] For detailed references various memoirs cited by Lorenz in *Zeitschr. Deutsch. Geol. Gesellsch.*, Bd. LVIII, p. 120, 1906 and by Cowper Reed in *Pal. Ind.*, New Ser., Vol. II, mem. No. 5, 1908, may be consulted.

[2] Reed, F. R. C. *Rec. Geol. Sur. Ind.*, Vol. XLI, pt. 2, pp. 106–112, 19.

following species are represented [1] *Spirifer* (*Reticularia*) *curvatus*, Sp. (*Retic.*) *aviceps* Kays., *Cyrtina heteroclyta* Defr., *Spirifer speciosus* Schloth. var., and new species of *Platyceras*, *Pleurotomaria*, *Meristella*, etc. Although *Calceola sandalina* has not been recorded, the age of these beds appears to be Middle Devonian (Eifelian). Middle Devonian faunas corresponding in age to those of the Northern and Southern Shan States (Eifelian) are found further east in Yunnan [2] and Indo-China. [3]

We have thus an almost continuous record of Eifelian strata from Armenia in the west to the Chinese basin in the east. They indicate according to Grabau [4] the

> 'general direction of transgression of the early Middle Devonian Sea, which extended probably from the region of the Bosphorus [5] across Asia Minor and Persia, into the heart of Southern Asia along the Southern border of ancient Caucasia. That the ancient passage-way along the Himalayan geosyncline was again open at this time, is shown by the extensive development of the Eifelian fauna at its eastern end, in the Northern Shan States of Burma as well as the presence of this fauna in South-Western China (Yunnan) and Indo-China'.

The recently discovered Southern Shan States fauna constitutes a further link in this chain.

The record of the upper part of the Middle Devonian (Givetian stage) is less clear in Western Asia as well as in the Himalayan region. Certain it is, however, that a transgression in Givetian times flooded the present region of the Kwen-lun and Tian Shan mountains. Rocks of this age also occur extensively in China though the zone fossil *Stringocephalus burtini* has so far been found only in Yunnan. Up to the end of the late Middle Devonian (Givetian) times, however, there is no fossil record indicating that the western part of the Devonian sea was connected with the Chinese basin via the region north and east of the Tibetan region. In other words, the only connection seems to have been via the Himalayan geosyncline, where Eifelian strata are known.[6] This is significant in view of what follows.

UPPER DEVONIAN.

Exigencies of time do not permit me to consider the Upper Devonian here in detail, but one fact of great importance may

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[1] Sahni, M. R. *Proc. Twenty-fifth Indian Science Congress*, Pt. III, Abstracts, p. 114, 1938.

[2] Mansuy, H. Étude geologique du Yunnan oriental, II^e partie, Paléontologie. *Mem. Serv. Geol. Indochine*, 1912; *Ibid.*, Vol. III, fasc. II, pt. 1, 1914; Grabau, A. W. *Pal. Sinica*, Ser. B, Vol. I, Fasc. 2.

[3] Mansuy, H. Contrib. Carte Géol. Indo-Chine, Palaeont. (Sérvice des Mines, Hanoi-Haiphong, pp. 2, 3, 15–20, 1908).

[4] Grabau, A. W. Stratigraphy of China, pp. 155-156, 1923-24.

[5] Abdulla Bey. Remarques Géologiques sur le calcaire dévonien du Bosphore. *Boll. del R. Comit. Geol. D'Italia*, Vol. I, p. 187, 1870.

[6] Hayden, H. H. *Mem. Geol. Surv. Ind.*, Vol. XXXVI, Pt. I, p. 20, 1904.

be mentioned. It is that we have no record of Upper Devonian rocks in the Himalayan region, which was then presumably a land area. But Upper Devonian strata are developed in the Chinese basin, in the region north of Tibet and west of the Himalayas. It is, therefore, probable that the Upper Devonian fauna migrated eastwards from Western Asia via the marine basin north of Tibet while (as we have seen) the Middle Devonian fauna found a passage-way South of the Tibet region, i.e. via the Himalayan geosyncline. Against this, however, are the views expressed by Bailey Willis who considers that the Tibetan region was an island practically throughout the Palaeozoic era. Bearing in mind this conflict of views we can merely emphasize that final judgment can be left only to future work.

CONCLUSION.

I have attempted to present before you a panoramic view of the sequence of geological events that have moulded the palaeogeographical history of the Asiatic continent and more particularly of the Indo-Burmese region, from the Vindhyan to Devonian times. This we may now summarize. If the mighty Himalayan ranges constitute an effective barrier at the present day separating the mountain tracts of the north from the plains of India, the hand of destiny has assigned this rôle to that region, in one way or other, almost since the dawn of geological time; for even in the Vindhyan period we recognized the germs of a great geosyncline, which was to dominate the geography of Southern and Eastern Asia practically throughout the Palaeozoic era. During the Cambrian this geosyncline girdled the Northern Hemisphere from Western North America to the shore of the Dead Sea. Since then this ancient Mediterranean Sea has waxed and waned with varying fortunes at different periods. The Ordovician and Silurian saw its retreat from the whole of Western Asia. But that a marine connection was maintained during these periods with the European seas is proved by the presence of many European species in the Himalayas, in Upper Burma and in the Chinese basin. A new passage-way across Central Asia had, in fact, opened up and remained so till the close of the Silurian. During the profound Middle Devonian transgression the site of the ancient Cambrian geosyncline (in Western Asia) was rejuvenated, so to speak, and once again formed the route of migration of European faunas.

The Himalayan region remained a marine area practically throughout the period under consideration, except perhaps during the Middle Silurian when a world-wide negative movement of the seas set in, and in a lesser measure during the Upper Devonian, when according to the available evidence the sea temporarily retreated from the Himalayan geosyncline.

The problems of divergence between the Himalayan and Burmese Ordovician faunas, of the relationship between the Iranian, Indo-Chinese and Himalayan Cambrian faunas, of the invasion of Bohemian or Mediterranean faunas into Asia, have been raised and discussed in the light of their palaeogeographical bearing, but I can hardly claim that suitable solutions have been attained. Considering the importance of the problem one can only regret that our knowledge of the Himalayan palaeozoic faunas, already meagre, has not been supplemented in any substantial measure by fresh discoveries, and the void remains.

Our knowledge of the continental boundaries during the periods under review is far from conclusive though restorations have been suggested by various authors. But we know enough to be able to say that the seas and continents have undergone profound changes through the vicissitudes of Geological time and the map of the world has altered almost like the varying stages of a child's jigsaw puzzle. In short, one might say that our mother earth is like a ball of plastic clay in the hands of a Modeller and the same Modeller that makes and unmakes the destinies of men and races also shapes and unshapes the oceans, the great continents and the islands that stand like sentinels on the ocean highways. The impact of Geological forces has changed the face of many continents and if a mere man of science may dare to preach a moral to the warring nations of the world, in this age of stress and strife, it could be said that the continents which they seek to conquer and possess are, in the infinitude of time, like the patterns of a cloud—an illusion and a chimera.

SECTION OF GEOGRAPHY AND GEODESY

President:—S. M. Tahir Rizvi, B.A., Ph.D., M.A., F.R.G.S., F.R.Met.S.

Presidential Address

(*Delivered on Jan. 6, 1941*)

CONSERVATION OF INDIA'S NATURAL RESOURCES.

Ladies and Gentlemen,

I thank you most heartily for the honour you have done me by electing me to preside over the deliberations of the Geography and Geodesy Section of the Indian Science Congress of this session. I am conscious of the great responsibility placed on my shoulders but, counting upon your kind co-operation and forbearance, I shall try my best to fulfil the task in as best a manner as could be possible.

Introduction.

Few problems in India are of more vital importance than the conservation of the natural resources of the country on a planned basis. To-day, public consciousness needs more than at any other time of Indian history to be rightly educated as to the existence and utilization of abundant natural resources of the country. I have, therefore, selected the conservation of India's natural resources as the subject of my address as it is a subject of general interest as well as of vital importance to our nation.

Whereas the growth, greatness and survival of a nation depend largely on the natural resources of the country, their conservation seeks to insure to society the maximum benefit from their use. Thus conservation of natural resources such as soil, forests, water and minerals, without which the very existence of a nation may be at stake, should, therefore, unquestionably be one of the most important matters for the consideration of those who are entrusted with the responsibility of formulating programmes of national reconstruction.

Conservation of natural resources is a timely field of action in India. The growth of population in this subcontinent has been accompanied by an unprecedented destruction of the

natural landscape. Moreover, as the country awakens politically and the limits of its resources and the character of its need begin to appear more fully, the necessity for greater care in the utilization and renewal of resources becomes imperative indeed. The movement is a timely one being in line with a worldwide concern regarding the material bases of national well-being.

There is no doubt that conservation is a field of vast national importance and of such magnitude and range as to demand the co-operation of nearly everyone. Contributions to its theory and practice may be made by the layman and the scientist, by the philosopher and the practical man of affairs, by the social scientist and the natural scientist. In one way or another, each of the natural and social sciences can give, and, indeed, is giving, some assistance, directly or indirectly. The scientific geography though still in its infancy in India is contributing to the field of conservation both theoretically and practically. Studies in systematic and regional geography are greatly helping to build up our knowledge of our natural resources and the problems arising from their exploitation. Geographers are also taking an active part in the practical application of their viewpoint and techniques to problems facing the nation. Moreover, they are imparting useful knowledge of the principles and practices of conservation in the colleges, and in a small measure at elementary and secondary schools. The rising generation is, therefore, learning largely through geography teachers and text-books about the aims and practices of conservation. However, it is not meant, in any sense, to imply that teaching in this field is exclusively the function of geography.

As the subject selected by me is a very wide one it would not be possible for me to discuss it fully in the short time at my disposal. I have, therefore, limited my address to three aspects of the problem, that is to say, conservation of soils, forests and water resources.

Soil.

The soil of a nation is its most material heritage. It nurtures the ever-flowing stream of vegetation from which men and their animals derive their sustenance. The preponderance of the world's organic raw materials as well as its food supplies arise from soils through the practice of agriculture. The great civilizations of the centuries have rested fundamentally upon uncountable millions of fields planted and tended by man.

The civilization of this country has been and is based upon its soil resources and great agricultural industries. Our country taken as a whole possesses such a combination of soils and climates that it suits admirably to agriculture and no less than

nine-tenths of the population of India to-day is engaged, directly or indirectly, in agricultural pursuits. Soils are subject to certain changes when cultivated or pastured. Change in itself is not a critical matter since eternal change is a fundamental law, for, were this not true, it is doubtful if man could have survived. The critical aspects arise when changes in soils that are subject to human manipulation are left to take a degenerative course, or are improperly directed, and when known means of maintaining the soils near their virgin level or raising them to higher levels of productivity are not employed.

These critical aspects obtain rather generally in India. At the end of several centuries of agriculture and pastoralism, the soils in India are in a lower state of fertility than our scientific and practical knowledge should tolerate. Especially serious is the fact that some soil areas have so seriously deteriorated that their early reclamation will be extremely difficult and costly, if not nearly impossible. This is particularly true of the gross physical destruction of the soil body occasioned by erosion. More subtle but almost equally serious is the state of chemical, physical and biologic degradation into which we have allowed our soils to drift. The causes are many. We have not fully appreciated either the limitations or capabilities of our soils. They were and are looked upon much as a mine, as simply possessing a store of plant food: when these had been extracted there was little we could do except abandon the land until it somehow recuperated. Moreover, since the keynote of Indian agriculture has been primarily self-maintenance, systems of cropping were so shaped as to yield the maximum results regardless of the tolls on the soil. Whatever the causes the general results are equally deplorable.

Soil Erosion and its Causes.

Within the last few years we have learnt that erosion, far from being a harmless or completely beneficial process in all its manifestations, is a living, constant menace to our own security and the security of posterity. We have learnt that the process does not remain at geologic norms when human factors intervene in the natural order of dynamics pertaining to the earth's surface. We know definitely that man's misguided use of the land has accelerated this ancient earth-process until it has overwhelmed enormous areas of once fertile land and impoverished even greater areas. In the light of this knowledge erosion becomes a matter of concern to everyone; since it constitutes a threat to the principal factor in our country's security—our indispensable agricultural lands.

Accelerated erosion is the result of conflict between man and nature—of man's necessary interference with natural processes of land stabilisation in order to provide himself with the necessities

of existence. Under a blanket of vegetation, nature protects the soil from the erosive forces of wind and rain and her protection is almost complete. Soil losses under natural conditions of vegetation cover are negligible—so small, in fact, that normal processes of soil-building are generally adequate to compensate for them.

Faced with the problems of existence, man strips away the protective cover of vegetation, and thus rudely interferes with nature's balance. Soil is exposed to winds and rain and rates of erosion are increased almost enormously. Cultivation still further exposes the soil to the cutting force of wind and flowing water, again accelerating the rates of wastage. In the one instance—under natural vegetative conditions—therefore, erosion is normal or geologic; in the other—under cultural practice—the process is speeded to abnormally destructive rates. Soil erosion has thus become a worldwide problem owing to the way in which ploughing and grazing have destroyed the plant cover which Nature originally provided to protect the earth's cover.

Types of Erosion.

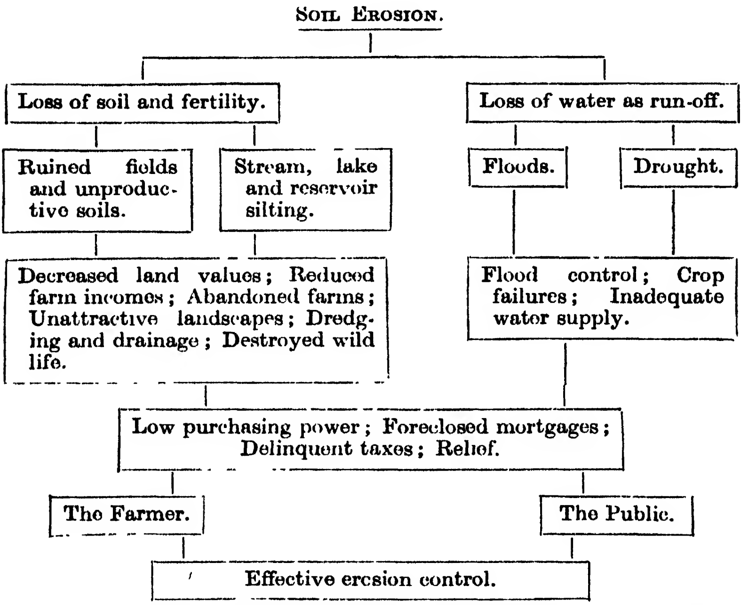
There are, broadly speaking, three types of erosion: sheet erosion, gully erosion, and wind erosion.

The first is the most widespread and dangerous, being the principal agency of soil impairment, for it can do great damage before it becomes apparent to the farmer. Sheet erosion characteristically proceeds so slowly that farmers themselves generally have not understood it and, accordingly, have given little attention to its effects until out-croppings of infertile sub-soils or bed-rock appear over their sloping fields. The process involves removal of thin sheets of soil over the entire extent of unprotected areas with every rain heavy enough to cause water to flow across the slopes.

The first effect, which often goes unnoticed, is the removal of the finer soil particles in suspension, leaving the coarser particles behind. These finer parts of the soil are valuable because they help to bind the soil into crumbs. The capacity of the soil to retain moisture and soluble plant food depends largely upon this crumb structure. If the finer particles are lost by sheet erosion the soil deteriorates. In extreme cases the whole of the top soil is removed bodily, leaving behind only an infertile sub-soil of clay or gravel. Sheet erosion is common throughout India except in areas irrigated by canal or well, but is of course more serious on all sloping land.

Gully erosion is much more obvious and it is easy enough to see and understand the deadly malignancy of it. This type of land devastation frequently follows after sheet erosion as a later stage of deterioration. When there is not enough vegeta-

tion to impede the run-off of storm water, the proportion of rain not absorbed by the soil finds its way downhill in a series of small torrents. A vicious circle is set up, because each channel is cut wider and deeper by every succeeding downpour, and the torrent tears soil from the sides and bed of the gully. Loss of soil is increased by the cutting back of each branch gully into the higher ground behind. Deeply gullied 'bad lands' are to be seen in many parts of India whenever the level of the land surface is at all high above the bed level of nearby rivers.



(Chart showing how soil erosion affects the general public as well as the farmer.)

The Jumna basin provides one of the finest examples of gully or ravine formation in the world. In many parts the vegetation on the neighbouring lands after centuries of abuse is of a very poor description and the rainfall flows away with great rapidity thereby increasing the volume and the violence of the torrents and leaving their beds dry after a few hours of the storm. The accumulated effect of this flood and scouring in a hard Kanker soil has resulted in the banks of the Jumna and the Chambal being violently eroded during the last few hundred years with a corresponding sinking of the water level.

A rough calculation has shown that the total soil erosion of the Jumna-Chambal basin is equivalent to the removal of

12 cusecs or ½ ton of soil per second day and night without stopping for the last 1,000 years.

Both sheet and gully erosion are caused by water action but another form of erosion results from wind action. Open treeless plains of dry light soil are particularly susceptible when the natural grass cover is destroyed by ploughing or heavy grazing, for the exposed soil can then be whipped up and carried away by strong winds.

Ground thus disturbed develops a peculiar topography of low hummocky sand-hills on top of which deep-rooted bushes survive after all other vegetation has given up the unequal struggle. Actually India as a whole does not suffer from wind erosion to the extent that has occurred in the so-called 'dust bowl' of the middle Southern States of the United States of America, or in the inland livestock ranches of Australia or along the southern fringe of the Sahara. But in certain restricted areas in India it is a definite menace, for instance, just north of Campbellpur in the Attock district and along the Delhi-Lahore road near Doraha.

Widespread Effects of Erosion.

The harmful effect of these three forms of soil erosion go far beyond the removal of the valuable top-soil on which plants depend for their nourishment. One direct effect is of course gradual decline in crop yields which more than off-sets any gains brought about by seed selection and manuring. The direct effect in pastures and grazing lands is to reduce the capacity of land for carrying livestock, for good pasture may carry a cow per every two acres, but the eroded pasture land may not keep a cow properly on ten acres.

Erosion also has indirect results, of which the most important for us in India is the dumping of large quantities of sand in the river-beds so that the bed must inevitably be raised and thus aggravate the effect of floods.

Another effect is to increase the severity of the intervening drought periods. This is because each small stream in the foothills discharges perhaps 80 or even 90% of heavy storms within an hour or so, and only a very small part of the rain soaks in the bare ground.

Apart from the rivers therefore the level of the water-table underground is apt to shrink because the amount of percolation or seepage through the soil into the underlying rocks and subsoil is less. Springs and wells are fed by reserves of water stored underground, but these reserves dwindle because eroded soil will not allow rain to penetrate underground, so that wells dry up, springs are reduced to a trickle, and rivers that once flowed all the year round now fail in the dry period.

Aside from the destruction above mentioned, erosion carries with it consequences of vast importance to the permanence of investments of large sums of money in navigation, power, municipal water supply and irrigation developments.

Deforestation and Soil Erosion.

It is admitted by all authorities on erosion that one of the greatest calamities which have overtaken mankind has been the destruction of the forest and the consequent erosion of the land surface. This has already destroyed the fertility of many lands and is at the present day exercising a great influence on the destiny of the people. Deforestation and soil erosion not only intensify floods and reduce the cold weather discharges of surplus streams but they threaten the sub-soil water supply and impoverish the soil and reduce the output of agriculture. In fact, these two demons threaten the very basis of civilization and of human life.

Erosion results from the misuse of the surface covering of the earth, whether it be by the destruction of the forest which covered it, by the misuse of arable or pasture land, by bad methods of cultivation, by burning or by over-grazing.

There is sufficient evidence to show that India is faced with the very grave danger of her river catchments being denuded to such an extent as to increase floods during the periods of heavy rainfall, decrease river supplies for irrigation and navigation during the dry season, increase siltation of the rivers, and throw large areas out of cultivation.

America is now fully alive to the disaster which threatens her and has even formed a special department of engineers to deal with erosion while her foresters are actively fighting deforestation.

There are many indications that in parts of India conditions are, at least, as bad and, sometimes, worse than they are in America. For instance, the Ganges carries to the sea eight times the quantity of silt carried by the Mississippi and that from a catchment area less than one-third the size.

It is not without significance that the highest recorded flood in the Ganges occurred in 1924 and the lowest record of winter discharge occurred in 1929. Records of the Ganges for over 100 years are available and this period is long enough to exclude all seasonal cycles.

American Research.

American research has found that during the years 1935-37, the rate of run-off from completely denuded lands, such as is only too common on the banks of some of our rivers, such as the Jumna and the Chambal, is twenty times greater than it

is from preserved forests. During one month of the flood season in Southern California a watershed, which had been burnt out 4 years previously, was denuded of 120,000 cubic yards of top soil or a depth of 1·4 inches per square mile. On a similar watershed burnt out 19 years previously, the denudation rate was one-tenth of this while in a watershed fully protected for the last fifty years the same rainfall only gave a denudation rate of one-thirtieth of this.

The fertility of the soil lies in its top crust and the removal of 1·5 inches of the surface soil which Nature takes a long time to create, amounts almost to a disaster. The unproductiveness of newly exposed sub-soil is well known and one might almost say that once the surface has been destroyed, fertility has gone for ever as far as the present generation is concerned. It seems quite reasonable to suppose that one of the most important factors contributing to the low crop yield in India is erosion by wind due to the absence of wind breaks.

Examples of Damage.

It is generally known that there are extensive waste and ravine lands in Agra, Muttra, Etawah and the adjoining districts. The ravines of the Jumna and the Chambal river form a practically compact mass the extreme length of which is 70 miles and the width about 13 miles in the centre. It is estimated that in the Etawah district alone there are about 120,000 acres of ravine land and there are large ravine areas in Agra, Muttra, Jalaun and other districts.

The Description of Ravines.

The banks of the Jumna and its tributaries are now so completely drained that the greater part of the area has become almost destitute of vegetation. Cultivation beyond this desert belt is precarious even in years of normal rainfall and the presence of these ravines renders irrigation impossible. Throughout the whole extension of this ravine land no water is to be found except in deep wells and in the main rivers. The dry belt is increasing in extent, as the ravines eat into the flat lands at the heads every year. With the hardening effect of the tread of cattle and rapid drainage the monsoon rains penetrate to a depth of only a few inches and this quickly dries up leaving a soil almost destitute of moisture down to the water table 100 feet or more below. It has been found that occasional scattered trees now found are of great age which have continued to reproduce themselves by coppice shoots and their root-systems have kept pace with the sinking of the water level, drawing up their necessary moisture from great depths. Natural reproduction invariably dies down as soon as the rains cease. The

natural vegetation of the ravine land has been destroyed by uncontrolled cultivation wherever the soil is fit for this, and by uncontrolled grazing, reckless destruction and by fires elsewhere. Large areas are now almost treeless but the original natural vegetation was undoubtedly forest and is still forest except in Kanker and Usar soils. The vegetation consists of small trees, thorny bushes and grass.

The Panjab Siwaliks.

Some of the worst erosion is evident in the Panjab Siwaliks, a range of hills skirting the Himalayas where the hill grazier has accompanied or followed the wood-cutter and effectively denuded the soil of its protective plant cover. In many places damage is not confined to the eroded slopes, further destruction being caused by torrents (chos) formed by gully erosion that sweep down the slopes during the monsoon. The cho is characterized by the steepness of its gradient and the violence and irregularity of its discharge. The torrent carries much suspended material which is deposited on the less steep lower slopes in a characteristic detrital cone which continually increases in radius and width. The chos debouching on to the cultivated sandy plains silt up the original drainage channels formed when hill erosion started, and the floods are forced out over wide areas. The floods subside as suddenly as they start, and all the water is lost to the land.

There is evidence that a hundred years ago the chos ran between well defined banks, and in some places perennial streams that could be used for irrigation issued from the hills. To-day, floods are the only source of water. Much of the subsequent erosion has been due to intensified exploitation that occurred when British rule secured some measure of prosperity and security. Reclamation might possibly be effected by closure of the land so that first grass, and then forest, could be re-established, but all the land is required to support the people, who have the right to use it, and the authorities have a natural aversion to interfering with jealously held rights. A drastic reduction in the surplus grazing animals is indispensable before any conservation programme can become effective.

Necessity for Control.

Accelerated soil erosion and its control presents the country with a physical land crisis of enormous importance to the continuing welfare of agriculture in particular and the entire social structure in general. Moreover, beyond the most acute crisis of the whole land problem, there exists the physical fact that there can be no permanent cure of floods or prevention of stream and reservoir silting until run-off is better controlled,

all the way from the crust of ridges down across the watersheds where floods originate and silt loads are picked up, on to the very channelways of streams, which have limitations upon their carrying capacity.

Control of erosion is the first and the most essential step in the direction of correct land utilization. It must be performed if the country is to avoid early arrival at an inconceivably bad land situation. The United States of America and the Union of South Africa have reached the same conclusion and are now engaged in a fight against erosion in their country. The Italian Government is carrying out an enormous land reclamation and conservation programme. Japan for many years has been spending many times the value of numerous critically eroding areas in order to protect indispensable valley lands from the erosional *débris* issuing from such sore spots. There is no reason to assume that India can better afford to neglect this gigantic problem of waning soil productivity than any other country.

Forests.

One of the most valuable assets of India is her forests both from the point of view of material wealth they represent and their incalculable value to livestock and agriculture, providing food and giving natural protection against floods and dust storms. Their beneficial influence on climate, on the conservation of the water supply, on the flow of streams and rivers and the prevention of the erosion of soil needs no emphasis.

To realize how important it is to retain the natural protection afforded by forests, one has only to look round at other countries and to see how large areas of land unsuited for permanent cultivation which were alienated from forests and made into farms have now been abandoned to waste and desolation and in others how forest denudation has led to flooding and dust-storms which have brought widespread destruction and misery in their trail.

With the steady growth year by year of knowledge of the importance of the part played by forests in the prosperity of countries, particularly an agricultural land like India, the problem has become of national interest.

The character of the forests in India is largely governed by rainfall and elevation. Where the rainfall is heavy evergreen forests are found. Under a less copious rainfall deciduous forests appear, containing teak, sal, and a great variety of other valuable trees. Under a still smaller rainfall the vegetation becomes sparse, containing acacias, tamarind, etc. In the Himalayas, sub-tropical to arctic conditions are found, and the forests contain according to elevation, pines, firs, deodars, oaks, chestnuts, etc. It has been the experience of all countries

that the natural processes of growth and reproduction by which forests are kept alive are incapable of keeping pace with man's destructiveness, hence it is necessary to take special measures in the ultimate interests of the country to preserve its forests from reckless destruction.

Forest Influences.

If you read history, you are bound to believe in the prosperity of the ancient kingdoms, and if you compare their ancient grandeur with their present decay, and their ancient wealth with the amount produced to-day, you can only be driven to one conclusion, and that is that the present decay of these countries is very largely due to the deterioration of the moisture that lies in the earth. Now, just imagine for a moment, what has happened to Persia. Take the example of the palace of the King of Kings, Darius, who at one time reigned practically over the whole eastern world. Can you imagine a man occupying his position, building his palace in the desert? But to-day, if you see the ruins of the palace of Darius in Susa, they stand in an uninhabited wilderness. Mesopotamia, which for generations produced all the revenues of Persia by which that country was able to wage wars against the Romans, has degenerated into a dreary waste and the hanging gardens of Babylon are a rubbish heap. No doubt the degradation of Babylon was partly due to the destruction of the irrigation works by the invasion of the Mongols, but already at that time, the irrigation system of Mesopotamia was in a state of decay on account of the destruction of the forests on the hills, and the bad regime of the Tigris and Euphrates which supplied the water for the finest irrigation system in the world, a vast system with which the Panjab at the present day cannot compare. The same history has been repeated all over the world. In Greece, Anatolia and Spain, the destruction of the forests has seriously interfered with their climate, with their cultivation, and with the moisture content of their soil. So much has this been the case in ancient history that it has been stated that deforestation, by the lowering of the moisture content of the soil, thus decreasing the water supplies of the country, has done more damage than any war, and has resulted in the destruction of the greatest empires.

Utility of Forests.

The history of modern civilization is founded upon wood. Despite the increased use of iron and steel and their replacement of wood for many purposes it is a proved fact that the consumption of wood per head of population has been steadily increasing, unless limited by supplies, in all countries in proportion as the material prosperity of the people has increased.

In Europe and America the consumption of wood *per capita* is over 20 cubic feet; in India it is under 2 cubic feet. Prosperity involves increased wood consumption and to supply the ever-growing requirements of the people is one of the most important of the functions of the forests. The great mass of the population of India are not townsmen but agriculturists who live in the country, and those of them who are fortunate enough to live in the vicinities of forests know that the forests mean to them much more than the mere production of timber and that the success of their cultivation of field crops is intimately bound up with the existence of the forests. A supply of firewood is one of the most essential needs of the people, and where there are no forests from which firewood can be obtained the people have been driven to burn cowdung which should have been used to fertilize their fields. There are innumerable cases where the destruction of forests have led to the burning of cowdung with serious adverse results on the cultivation of crops. But apart from yielding firewood and poles for building houses the forests yield many other kinds of produce which the agriculturist wants. They yield him timber for making his ploughs and other agricultural implements, bamboos for fencing and other purposes, thatching grass, grazing for his cattle, edible fruits and flowers which help him to live more especially in times of famine, fibres for making ropes, medicines for the sick, and many other articles.

There are numerous indirect benefits conferred by forests whose importance is not readily understood.

Firstly, forests increase the relative humidity of the air, reduce evaporation, and maintain a more continuous degree of moisture in the soil. They also tend to increase precipitation of moisture. These effects are important from the agricultural point of view in a hot dry climate such as is prevalent over the most part of India.

Secondly, forests assist in regulating the water supply by reducing the violence of floods and by rendering the flow of water in rivers more continuous. They further assist in preventing erosion. On denuded soils the rainfall rushes off the surface in torrents which gather in volume and sweep away the fertile top soil of the land. On forest-covered areas the rain-water is held up by the crowns and roots of the trees and the more spongy forest soil, with the result that it percolates more slowly into the ground and emerges in the form of springs which supply the rivers more continuously with water. In areas where deforestation has been rapidly proceeding many of the streams which used to run all the year round have now dried up and this has had a bad effect on field crop cultivation. Innumerable examples of the serious effects of forest destruction on the fertility of the soil and water supply could be quoted from all over India. This valuable effect which

forests have in reducing the effect of erosion and floods is not, however, confined to the areas in which the forests are situated. The disastrous floods in the plains have been due to the destruction of the forests in the river watershed. Such floods tend to get greater and greater each year as the destruction of forests in the hill areas in which its tributaries have their source proceeds and unless this progressive destruction of forests is checked the time may one day come when still more disastrous effects of flood will be experienced.

Thirdly, forests reduce the velocity of wind and protect adjoining fields against hot dry winds. They afford shelter to cattle and generally reduce the temperature of the air and render the climate more equable.

Fourthly, forests increase the artistic beauty of the country and exercise a restful effect on the human mind, thus assisting in furthering the happiness of the people.

Forest and Floods.

It has been often stated that a forest cover in a drainage basin materially reduces floods but forested areas are not free from the hazard of flood damage. Although the effect of forests upon run-off has often been overstated their effectiveness should not be depreciated.

Adequate flood protection is largely dependent upon engineering structures but the forest cover should be considered as a supplementary protective measure. A closely forested area with its absorptive leaf-litter delays run-off somewhat and gives greater seasonal uniformity to the discharge of the streams. This slight retardation of run-off may serve to reduce floods provided the subsequent rains are delayed a sufficient length of time to permit the lowering of the water table and a drying out of the litter. If the absorptive capacity of both the litter and the soil is reduced because of saturation heavy downpours of rain will cause floods. Probably the most important effect of the forest cover is not in its effect upon surface run-off but upon its protection of the soil, which in rugged areas is susceptible of removal, and when both the forest cover and the absorptive topsoil have been removed, all rains, no matter what their spacing, yield rapid run-off. These indirect results are of major importance in the prevention of floods and in the maintenance of reservoir capacity whether the reservoirs be used for flood prevention or for other purposes.

Deforestation in India.

There can be little doubt that there were forests stretched over the greater part of India. In the Vedas, the earliest religious writings of the Hindus, in the epic poems of the Ramayan and the Mahabharat, references are made to dark, dense forest

areas situated in the Gangetic Plain, now a vast expanse of cultivation and for a thousand miles or more devoid of forest growth. Similarly the records of the wanderings of Chinese pilgrims (about 600 B.C.) frequently speak of miles and miles of very dense forests in the now almost treeless districts of Gorakhpur and Western Bengal. As late as the sixteenth century the Moghul Emperor Baber hunted tiger and other big animals of the forests along the Jumna river, in areas which have now become barren ravine deserts of stunted thorny bushes.

In the turbulent days of early Indian history with the rise and fall of dynasties and powers, the areas of forest fluctuated, shrinking to make place for cultivation with the advent of a strong ruler, increasing again with the collapse of central power, or when wars, pestilence and famines reduced the density and pressure of population. Thus we still find ruined and long forgotten cities in some parts of Indian forests. With the advent of the British rule in India, resulting in a great increase of population, with the attendant demand for timber for agricultural implements, constructional purposes, etc., a fierce onslaught was commenced on the forest areas and by the middle of the nineteenth century all traces of primeval forest in the Gangetic Plain disappear except in the mountainous regions. Thus the destruction of the forest area, or rather the diminution in the area of the forests within the boundaries of India, has been going on at a very great rate during the last 150 years. To give you an instance, when the Emperor Jehangir built the castle of Nurpur for his Queen, Nur Jehan, the Light of the World, he writes in his memoirs that forest was so thick that a bird could hardly spread its wings. But if you go to that place to-day, you will see nothing but a denuded hill country, with hardly more than a few tufts of grass and thorn bush on which a few goats eke out a miserable existence. All that has happened in a period of not more than three hundred years; in that time the dense forest which clothed the outer Himalayas has been reduced to a negligible amount.

Due to the reckless extermination of forests by man or through excessive grazing, fires or over-cultivation, the area covered by forests in the United Provinces has been reduced to 4% of the total area of the province and is confined almost entirely to the hills and submontane region. This in itself by all standards is inadequate to meet the diverse demands of a progressive country as it has been estimated that about 20% of the area of a country should be covered by forests.

Necessity of Forest Protection.

There are two main reasons why such protection is necessary. Firstly, forests require protection from man. It is a common

failing in human nature that whenever any product is found in abundance its use is abused without thought for the future. The steady destruction of forests which has taken place in the old and new world is a striking example of this attitude on the part of man. The great Indian epics tell of the mighty forests which used to exist in the Gangetic Plain. At the present day there are only remnants of forests left which are confined to the hilly tracts of the country, and over most of the plains the people are put to hardships as they cannot get the forest produce on the supply of which the success of their cultivation depends. The reclamation of forest land by bringing it under the plough is a sign of agricultural progress as the people must have food to live and the greater the area under cultivation the better. But there are large areas of forest land which have been cleared for cultivation, which should never have been cleared as the soil is poor and incapable of supporting field crops year after year. Good forests can be grown on land which is poor from the agricultural point of view, and on such poor soils forests should be retained because they are more valuable than field crops. The practice of shifting cultivation under which forest areas are cleared and burnt, cultivated for two or three years, and then abandoned, has been responsible for destroying large areas of forests.

Apart from the clearing of forest land for purposes of cultivation there is another factor which has been responsible for the destruction of numerous forest areas in the country, and that is that, left to himself the villager takes no care of his forests. He hacks down the trees indiscriminately and allows his cattle and goats to graze all over the forest thereby preventing any new trees from growing up to take the place of those he has removed. In how many thousands of villages can you see areas of barren waste land which formerly were covered with useful forest and which now do not yield even a scanty supply of grass? It is thus sufficiently evident that forests must be protected from the thoughtless acts of ignorant villagers who would otherwise destroy the forests with dire consequences for future generations.

Forest Conservation.

Forest conservation is a field of vast significance in Indian life. The services which forests can perform are numerous and their influence far-reaching. Moreover, the renewable character of forests makes for a very practical phase of conservation. With sufficient forethought, the country's resources can be kept at a level more nearly commensurate with its needs for wood products and other forest services, and, at the same time, much of the land which is now unproductive but suited to growing trees may be put to use.

Water Resources.

One cannot imagine man separated from water any more than one can imagine him separated from land. Water is an essential part of his being. He uses it in innumerable ways and because in areas of dense population he has been favoured with it, frequently he spends it recklessly, thinks of it as he thinks of air as an unlimited requisite of existence, and gives little heed to its value. In drier regions water is held of great value, and stringent laws governing its use are formulated.

The place of water in the lives of people in arid lands may be realized by the frequent rain ceremonies of the Hopi Indians and by the repeated references in the religious literatures of desert peoples, as the Bible and the Koran, to water as a blessing and to paradise as a place where there is abundant water.

Our water comes from precipitation, and the average rainfall for India is about 42 inches per year. This average will lead us easily to the total amount of water received by the country in one year but it tells nothing about the distribution.

The rainfall varies from almost nothing in the desert tracts of Rajputana to over 100 inches in the outer Himalaya and is profoundly affected by elevation and the distance from the sea. Most of the annual rainfall takes place in July, August and September during the summer monsoon; April and May are dry and intensely hot; the autumn is dry and in winter very little rain falls. Towards the north-west the rainfall decreases and the Panjab, formerly a desert, is now irrigated by a network of canals which take their origin from the rivers of the Himalayas.

In regions of scant water supply, conflicts are likely to arise over water rights, and frequently in densely settled regions there must be a choice between its various uses. One arrangement of the uses of water in order of influence or importance is as follows:—

1. Atmospheric moisture indispensable to organic life.
2. Drinking water for man.
3. Water used in agriculture and animal husbandry.
4. Water as a habitat of fish and sea-food.
5. Water used for generation of power.
6. Water used for mechanical and chemical processes in industry.
7. Water as a means for transportation.
8. Water as a medium for the removal and purification of waste.
9. Water as a recreational asset.
10. Water as a determinant of political boundaries.
11. Water used as ice.

India, for the manifold uses of water, must depend upon its rainfall. The 42 inches of annual rainfall cannot suffice

for all of them. About one-half of the rainfall is evaporated and goes back into the atmosphere as water vapour; about one-third of it forms the run-off, draining by streams and rivers to the sea. This is the visible water supply, and the greater percentage of the use in the above list arises from this portion of the water. One-sixth of the rainfall sinks into the ground and forms ground water; this is a less well-known but very important reservoir of water which acts as a stabilizer of lake levels and stream flow and a source of water supply for the plant growth.

The problem of the manipulation of the enormous amount of water which falls in India varies with the humidity or the aridity of the area. Evaporation, run-off and ground soakage are not uniform, and unwise practices may increase run-off to a danger point and destroy the balance set up by natural agencies. Among the many problems of water are the control of floods which, for example, have caused great losses of life and property in the eastern Gangetic Plain; the control of low water stages which have hindered navigation, as on the Ganges and the Brahmaputra rivers, or have caused losses of crops; its use for navigation, power, water supply for cities and towns, and the removal of refuse from houses and factories; the erosive tendencies of rain and streams; the silting of streams and consequent deposition when stream flow decreases; its use for irrigation; the maintenance of the ground water supply and the stabilization of the water table, and the use of water as a recreational appeal. A water policy of the country should be so established as to yield the greatest benefit possible from our water resources and be so regulated as to serve the greatest need. At all events, one needs take the stand that water is a highly valuable source, too precious to be wasted.

Importance of Water for Domestic Purposes.

Water is one of mankind's most essential needs. Primitive settlements were located around springs and water-courses, and when the water failed the people were driven from their homes. Palmyra, once a city of possibly more than 150,000 people, vying with Damascus for the trade between Egypt and Babylon and reaching great prominence under the reign of Queen Zenobia, consists to-day of a few ruins in a desert landscape while Damascus still exists. Both were oasis cities, but the drying up of the oasis at Palmyra spelled its doom. Later people learnt how to build aqueducts and transport water from distant springs and rivers. When gold was discovered in the Australian desert in 1892, and the towns of Kalgoorlie and Coolgardie were founded, the district was practically waterless. For a while the railway transported water to the towns at a cost of about Rs.15,000 a day. In 1903, a water line was

completed from the Darling Range, 350 miles away, and a delivery of 8,000,000 gallons daily resulted. So long are the pipes that they contain a month's supply of water; in other words, the water takes one month in travelling from Mundaring to Kalgoorlie.

Residents of the Indo-Gangetic Plain have not really appreciated the value of water as the dwellers in more arid regions have. The idea that there was an ample supply has been passed on from generation to generation. To-day it is necessary to combat the idea and treat water as a natural resource of limited though perhaps inexhaustible amount which must be conserved so that the supply at any one time may be adequate for our needs and particularly so that its misuse may not be a burden to future generations.

Sources of Water Supply.

Cities and towns in India obtain their water supply from many sources—lakes, tanks, wells, springs, tube-wells, and streams. Most rural towns and many urban localities depend on ground water for their domestic supply, and this comes to them in part through springs but largely through ordinary wells. In every rainfall where there is a surface mantle over the rocks a certain percentage of the water is absorbed by the soil (estimated average about 16%). This forms ground water. Its upper surface is known as the water table. The amount of ground water is much greater than is commonly supposed. It has been said that there is enough water under ground so that, if it were brought to the surface, it would form a layer probably 500 to 1,000 feet deep. The depth of the water table varies; in swamps the water table reaches to the surface, and in arid areas it may lie a hundred feet below the surface. Frequently, in the Gangetic Plain, water is struck before one digs to 25–30 feet. The water table depth in any single locality varies with the rainfall. A long period of drought takes a serious toll of the ground water, and the water table may be so lowered that it falls below the level of the well bottoms and the wells become dry. If the drain is not heavy the water table is generally brought back to its normal level by succeeding falls of rain. An extended drought, however, may bring serious damage by killing off the vegetable cover and subjecting the soil to wind and later rain erosion. In some localities, the water table has been lowered beyond the level of efficiency by stripping the vegetation cover, as in excessive deforestation, and in the processes of extensive cultivation, soil erosion, and ditching. For example, it is estimated somewhat roughly that the water table over large areas in India has been lowered by 10 to 20 feet by these methods. As an extreme example may be quoted the serious reduction in the base level of the Jumna River

where flooding and scouring has lowered its bed at Etawah 60 feet in the last five centuries with a corresponding fall in the spring level. The cold weather level of the river is often 120–200 feet below the surrounding country. The effect of this upon the ground water supplies is obvious.

Irrigation.

The arid and semi-arid regions of India like Sind, Rajputana and the south-west Panjab which are practically rainless have largely been rendered habitable and their latent resources made available to man by the use of water for livestock subsistence and irrigation. Water, a vital resource in any environment, assumes extraordinary significance in regions of less rainfall. In the arid and semi-arid regions of India, the conservancy of water becomes of permanent importance.

The chief characteristics of the Indian rainfall are its unequal distribution throughout the country, seasonal irregularity of precipitation and liability to failure or partial deficiency in many tracts. But, within individual tracts, remarkably wide variations in total annual rainfall are found. Such tracts include practically the whole of the Panjab and North-West Frontier Province, the United Provinces, except the sub-mountain regions, Sind, a large portion of Bihar, most of the Madras and Bombay Presidencies, omitting the coastal belts, and portions of the Central Provinces. The concentration of the principal rainfall in less than a third of the year places a very definite limit on the agriculture of the country. Thus our agriculture cannot afford to depend exclusively on rainfall and it becomes necessary to provide the agriculturist with suitable irrigation facilities.

The advantages of irrigation are numerous, the principal one being an increase in the yield of crops, the successful introduction of a stable agriculture in arid and precarious tracts, protection from and insurance against famines and scarcity and larger railway profits in agricultural provinces. The Indian canal system is by far the largest in the world. Of the total cultivated area of 280 million acres, no less than 60 million are irrigated from one source or another.

Greater demand for Water.

In view of the rapid increase in India's population and consequent increase of pressure on land the demand for more water for irrigation and for better distribution of the existing supplies becomes annually more insistent.

Water Power and its Conservation.

IMPORTANCE OF POWER: Mechanical power is the heart of modern civilization. Until means of mechanical power were developed man was unable to gain any definite control over the elements. The power-driven machine and its accompanying division of labour have almost entirely replaced the self-reliant workman of former decades. Man's welfare and comfort depend upon a continued and uninterrupted supply of power. Power is as essential a part of the necessities of modern life as are food, clothing, and homes. Indeed, without the use of mechanical power man's necessities and luxuries would be limited to the products of his immediate locale. The use of power allows him to live where he desires, to have his wants carried to his home, and to be transported to and from his work.

Sources of Power.

The principal sources of power available in India are coal, wood-fuel, oil, wind and water. Coal is India's most important mineral and India produces more coal than any other part of the British Empire with the exception of the United Kingdom. Most of the coal raised in India comes from Bengal, Bihar and Orissa (the Gondwana coal-fields). Outside these provinces, coal is obtained from Hyderabad State, Central Provinces, Assam, the Panjab and Baluchistan. Rajputana, Bikaner and Central India also contribute a small amount to the total coal supplies of India. Indian coal is thus very unevenly distributed, the deficiency being especially marked in the case of the peninsula. The absence of coal supplies coupled with the high cost of railway transport acted as a great handicap to the growth of industries and this had to be overcome partially by the use of hydro-electric power. The utility of forests as supplier of wood-fuel has already been referred. Many of the Indian forests are, however, confined to hilly tracts from which transport is a matter of great difficulty and expense. Moreover, it is doubtful whether the supply of wood-fuel could keep pace with the demand for it for industrial purposes. The position with regard to India's oil resources has completely changed due to the separation from India of Burma from which nine-tenths of the indigenous petroleum was obtained. As the possibility of the oil-bearing areas in Baluchistan, the Panjab, Assam, etc., must still be regarded as problematical, it would be unwise to place much reliance on this particular form of power.

Water Power.

As is evident the situation in India with regard to the supply of coal, wood-fuel or oil for purposes of generation of power is not quite so favourable as might be desired. There

are, however, fair prospects for the development of water power resources at its command. These have been limited so far on account of the seasonal character of the rainfall making costly storage works indispensable. In spite of this limitation, there are many potential possibilities of tremendous importance and within recent years considerable attention has been given to large hydro-electric power schemes. It is hoped that these schemes will not only serve the purpose of supplying power to the industries but also of extending the irrigation facilities in India.

Electricity for Villages.

We may even be tempted to dream of a time when every village within a reasonable distance from a hydro-electric power station will receive its supply of electric current to help the development of rural industries and increase the amenities of rural life. A start has been made and development on these lines has been undertaken extensively in the United Provinces. The power available at falls on perennial irrigation canals has been harnessed and converted into electrical energy. The power so generated is being utilized for commercial, domestic and agricultural purposes. But on the whole there are great obstacles in the path of realization of all these bright visions. The initial expense of most of the hydro-electric schemes in India is heavy. The rainfall being seasonal, costly storage constructions are necessary and the expenditure thus incurred makes it difficult to supply power sufficiently cheap. Whether science will be able to remove this difficulty, the future alone can show.

Floods and Flood Control.

Rivers come into existence as a result of precipitation falling upon the earth's surface, and have as their chief function the drainage of the excess waters to the sea. The lands receive their precipitation at very irregular intervals, and as a result the river with a uniform discharge does not exist. If all precipitation could be absorbed into the earth to become a part of the ground water and then discharged more or less evenly the streams probably could be confined to their channels. But an important proportion of the precipitation never becomes a part of the ground water but flows quickly to the water-courses, swelling the streams beyond their constraining banks. The placid stream fed largely by underground waters becomes in times of flood a raging torrent. With its capacity and its competency greatly increased, the river in flood becomes a powerful agent of destruction. Streams vary greatly in their capacity for destruction, but none is without its flood problem.

The fertile alluvial lands of the Nile, the Tigris-Euphrates, the Hwang Ho, and the Mississippi, the creation of their

respective rivers are repeatedly inundated, bringing death to millions and destruction to the works of man. The great rivers are, at the same time, the giver and destroyer of life and property. Smaller streams suffer from recurring floods, and the damage done is locally very great. The flood problem may be said to have its beginning when waters derived from run-off and underground sources spread beyond the restricting channel of the stream.

Flood Destruction.

The predisposition of the people to pre-empt the rich riverine lands for both agricultural, industrial and commercial purposes subjects them to the hazards of the recurring floods. Many of our large cities such as Delhi, Agra, Cawnpore, Lucknow, Benares and Patna were founded upon rivers when the watercourses were the principal highways of commerce. The use of lowlands for industrial and commercial purposes has caused excessive damage at times of flood, due both to the destruction of property and the suspension of business. Lands once used for private purposes are not easily relinquished, for the owners, especially if individual landholders, can hardly afford to abandon the properties to the use of the river. In such areas the recurring floods cause increased damage due to an increase in property values through the years. Urban areas subject to floods are abandoned only with great difficulty, for both industries seeking lowland values and people of the low-income class seeking low rentals are likely to locate on these cheaper lands along the rivers. Protection against floods is sought before abandonment is considered. If protective embankments prove adequate property values increase and the utilization of land is intensified. Then an unprecedented flood which breaks through the embankments causes great damage. The increased property damage in many cities is due to man's encroachment upon the river.

In agricultural areas the amount of damage depends upon the intensive economic use to which the land is subjected. The inundation of the crop lands may greatly reduce the yield or completely ruin the crop. The losses in rural areas are offset in part by the enrichment of the lands by the deposition of silts. The fertile topsoil eroded from the slope land within the drainage basin is deposited in part along the alluvial plains of the master stream and the major tributaries if they are aggrading streams. In some areas the spreading of coarse sand and gravels along a flood-plain may depreciate the value of the land for crops.

Causes of Floods.

Floods are results of many conditions working singly or in combination. Usually no single cause can be assigned the

whole responsibility. The immediate cause of most floods, however, is the excessive run-off from precipitation of high intensity, though many other conditions may be necessary to cause a great flood.

Flood Control.

To escape from the danger of floods various control measures either singly or in combination have been utilized to provide the necessary protection. Probably one of the earliest methods used to escape from floods was to evacuate the area at the first warnings of impending danger. Flight to safe areas could hardly be interpreted as flood protection but it did mean the protection of life and a limited amount of property. This method is still used when other methods of protection fail. Throughout the history of civilized man the fertile alluvial lowlands have been preferred areas of habitation; and, as high water menaced periodically the homes of the people the protecting dyke or embankment became one of the first methods of defence against floods. In other countries the flood problems are being attacked by various methods. One of the simplest and most individual methods of flood protection is channel improvement. Embankments are very commonly associated with other local preventive measures used along the smaller as well as the major streams. Further, the problem of flood protection may be partially solved by the use of preventive works in the head stream area of a drainage basin. Under certain conditions these storage reservoirs not only provide a solution to flood problems but may be used for other purposes such as water supply, power, irrigation, etc.

The Responsibility for Flood Control.

The control of floods is a responsibility which extends beyond the limits of the inundated area. Floods have no respect for political jurisdictions, just as political boundaries show little relation to hydrographic boundaries. Since flooded areas seldom coincide precisely with political areas the existing minor civil divisions such as tahsils and districts are unable individually to cope with the flood problem.

Individual Responsibility.

The flood problem begins with the formation of a tiny rivulet in the farmer's field. Its control is both a personal and a social responsibility. His personal interest is not confined to the hazard of floods on his farm but to the associated loss of soil as the run-off gathers into rivulets which converge into larger and more devastating streams, producing both water and soil damage.

The individual landowner, though he may have a humanitarian interest in the flood hazards of the drainage basin in which he lives, can do little towards the solution of the problem, especially if he lives beside a large stream. In rural areas when streams are small, individual farms may, by channel improvements and the construction of embankments, give protection to their low-lying lands. The clearing of a stream channel of driftwood, trees, and other obstructions may so facilitate the flow during the time of high water that the channel is widened, thus increasing its capacity.

Imperceptibly the personal responsibility of many individuals enlarges to a regional responsibility co-extensive with each important drainage basin.

Regional Aspects of Flood Control.

Planning for the best use of water resources is essentially a regional responsibility, the region being coincident with the drainage basin of the streams concerned. This concept of the planning region cannot be adhered to rigidly, for the transmission of water power in the form of electricity and the distribution of water for irrigation and municipal purposes extend far beyond the limits of drainage basin, and require a modification of the hydrographic region to include adjacent areas which constitute the peripheral sections of an economic region.

The problem of flood control, however, is rather strictly confined to the drainage basin. So long as control measures involve only riverine works the plan would require the co-operation of riverside communities but as control is extended to include preventive measures the whole drainage basin should be organized into a unit. The obstacles which make difficult the realization of this ideal are many, and probably will stand in the way of a strictly regional organization based upon the hydrographic basin.

Responsibility of the Provinces and the Central Government.

Where a drainage basin lies entirely within a single province the responsibility of handling the many water problems lies on it. Flood problems which involve two or more provinces may require inter-provincial co-operation in order that a flood-control programme may be extended to all parts of the drainage basin. The co-operation should include not only an inter-provincial agreement but also a uniformity of laws to facilitate the work connected with flood control. The State's responsibility also extends to finance the operations. For such purposes excessive expenditures may be justified, but there should be a careful scrutiny of all flood-control plans to make certain that the benefits to be gained equal or exceed the cost of the protective works.

CONCLUSION.

In conclusion I would emphasize that soil erosion in India has become a matter of vital concern and demands immediate attention. The improvement and fertility of Indian soils is another important problem. Planning on a wide scale to maintain soil fertility is, therefore, of supreme importance to the country in her campaign of rural reconstruction. The rapid increase in population since British occupation has greatly intensified pressure on the land, caused the cultivation of much unsuitable ground and shortened the resting periods between cultivation that are frequently necessary for the stability of tropical soils. The human population of India is increasing at the rate of about 4 to 5 millions per annum. Much of this increase is occurring in the tract where nature in the first place provided easy conditions for human settlement, namely rainfall not too heavy for the ordinary farm crops, and natural grasslands in which cattle thrive. Therefore, much of the weight of this increasing population is falling upon the tension belt where grassland can persist only under reasonable treatment, and if once destroyed cannot reinstate itself as easily as it can under a slightly heavier or better distributed rainfall. Hence over very large tract of country natural grasslands have already disappeared and village livestock are dependent upon bush and tree growth for their day-to-day existence. The amount of erosion caused directly through over-cultivation and over-grazing has become a national menace.

The conservation of forests and water resources of India are also vitally connected with the problem of ever-increasing population of the country and require a sound planning.

We should, therefore, recognize that problems of conservation are vital to each and every citizen of the nation. To one who is alive to the significance and magnitude of the problem of providing posterity with the means of a richer and happier life the conservation of the natural resources and their economic exploitation will appear to be the only possible solution. The development and administration of conservation projects will demand the full time of a large staff of experts maintained by the State, and it is gratifying to note that the Imperial Council of Agricultural Research and Provincial Governments are directing their strenuous efforts towards the execution of such projects, yet much cannot be achieved without the cordial support and co-operation of all citizens whether they are developing natural resources which they own privately or developing resources on public lands. The spirit of conservation demands that we recognize limitations to our personal rights in the utilization of gifts made by nature and render best services in the execution of local, provincial and national projects of conservation.

SECTION OF BOTANY

President:—SHRI RANJAN, M.Sc. (Cantab.),
DOCTEUR ÈS SCIENCES

Presidential Address

(Delivered on Jan. 4. 1941)

THE RESPIRATION OF PLANTS IN LIGHT

LADIES AND GENTLEMEN,

I am deeply sensible of the honour done to me by the invitation to preside over the section of Botany at this 28th Session of the Indian Science Congress. An honour like this is in itself a matter for gratification, but it becomes doubly welcome when the Congress happens to meet at Benares—the place of my birth and early education. I recall that fifteen years ago in this very city a great teacher and a kind friend, Professor R. S. Inamdar, occupied the presidential chair. Professor Inamdar was one of the founders of the School of Plant Physiology in India, and his memory as a Professor will for ever be cherished especially by his former pupils.

For the purpose of my address the Session at Benares is particularly opportune. Benares was and is the home of physiological research. The subject of my address which is on some physiological problems, though specialized, may perhaps interest a larger body of scientists.

THE THEORY OF PHOTOCHEMICAL ACTION

With the rapid advance of Science towards unravelling the mystery of light and bridging the gulf between light and matter, the subject of Photochemistry has, as rapidly, forged ahead. Invitro experiments have enabled us to get clearer conceptions of photosynthetic and photo-oxidative reactions. These reactions are, however, far more complicated in the living matter and my aim here will be to discuss whether or not photo-oxidations take place in the plants, as well, or, in other words, whether there is a 'Light respiration' as opposed to 'Dark respiration' in plants. But before we start on the problem itself let us briefly understand the general theory of photochemical action. Photochemical reactions are chemical reactions which are produced directly or indirectly by absorption of radiation. This was first propounded by Grotthus (1819) and, at a later date, independently by Draper (1841). Consider now a beam of light, composed of

various wavelengths, falling on a chemical molecule. Light consists of a series of periodic electro-magnetic disturbances of various periods of vibration. A molecule has also a certain period of vibration. Thus those light waves that have similar periods of vibration as the molecule will get absorbed and by so doing set up a resonant vibration in the molecule, which may reach an amplitude great enough to bring about a chemical change. Such changes may lead either to an increase of energy or to a decrease. A simple case of a former type of reaction is that of anthracene which, in light, polymerizes to di-anthracene and thereby the stored energy is increased. The assimilation of carbon by green plants is a case of complex reactions leading to an increase in energy. Photochemical reactions, however, resulting in the loss of energy may according to Weigert[40] be divided into (1) compound reactions and (2) catalytic reactions. In the case of the compound reactions the products of photochemical change are used up in another reaction. The photographic plate may serve as an example. By the action of light bromine is liberated from silver bromide thus forming an intermediate product. This then combines with the gelatine on the plate causing bromination of the gelatine. Respiration in plants, obviously, cannot come under this category, for in this case light is essential for bringing about the production of intermediate substances; it is not so in the respiratory process. On the other hand, there are numerous photochemical reactions which even in darkness, after a period of illumination, proceed at a speed greater than their thermal velocity. These show the phenomenon of 'After effect'. In such cases, in all probability, the increased quantum yield may be due to the formation of a catalyst. The well-known reaction of iodoform in chloroform, which liberates iodine in light and continues to do so even in darkness with a sufficient velocity which is, however, less than that in light will serve as an example. Such reactions will come under Weigert's second group, viz. catalytic reactions. All these reactions whether they be anabolic or catabolic must be preceded by an activation process. The ordinary vital reactions are slow for the simple reason that large numbers of molecules do not move with a very high velocity which is necessary for chemical reactions. Ordinarily, all the molecules do not move with such high velocities and thus the reaction goes on in darkness at a slow rate, but in light the molecules absorb radiant energy and thus increase their vibration velocity. According to the third law of dynamics, however, any reaction, that causes the diminution of free energy, must take place, for by so doing free energy is decreased. Thus after the vibration velocity increases, a reaction leading to the diminution of free energy takes place. Fig. 1 may serve to explain this point.

An unactivated molecule of $C_6H_{12}O_6$ will not oxidize to CO_2 and H_2O in the same manner as a ball kept on a roof will

not fall below. The ball has to be pushed to enable it to fall, so also the sugar has to be activated first before any katabolic reaction takes place. In both the cases there is a loss of energy.

FIG. 1.

Thus in all cases of such reactions, even though there be a final loss of energy, intake of a specific quantity of energy must at first take place.

THE PRIMARY PHOTOCHEMICAL PROCESS

With the development of the modern method of research in photochemical reactions the rôle of the primary absorption process in gaseous reactions has been of great importance in discussing the mechanism of the total (primary and secondary) photochemical change.

In this connection the quantum theory of Stärk [36] and its subsequent development by Einstein [13] is of great importance. Einstein assumed that absorbed light energy in amount equal to $Nh\nu$ should bring to reaction ν molecules, provided the time interval between the absorption of an energy quantum by a molecule and its subsequent reaction was small in comparison with the mean life of activated molecules.

According to Bodenstein [5] the primary effect of the absorption of light is the ionization of the molecules, but this

has been found to be invalid. Later Warburg [37, 38] and Nernst [24] advanced the view that dissociation of the molecules occur as a result of the primary photochemical process.

The phenomenon of light absorption by both the atomic and molecular systems have recently been studied by Franck [14], Rollefson [34] and others and it has been argued that in the atomic system, the atom in question is excited to a higher energy level and the excitation energy is utilized in the secondary reaction in presence of other gas molecules.

Similarly, for atomically bound molecules, if the absorption lies in the continuous region then according to Franck the molecules will be dissociated into atoms and one of the atoms will be in the excited state and in the presence of some chemically reacting component the excited atom will react and bring about the net photochemical change.

Recently, Bhattacharya [3] has shown that the rôle of the primary absorption process is activation or may be atomization of the molecules which is but a physical change in the state of the molecules. The electronic energy absorbed is subsequently transformed into kinetic energy which makes the molecules more reactive with the result that the initial rate of secondary chemical reaction is accelerated. Bhattacharya has further shown that the temperature coefficient for the primary process in photochemical reaction is unity.

In brief, the exact position of the present idea about the primary absorption process in photochemical reaction is that the absorbed energy is responsible for the initial acceleration of the thermal reactions in light and that the photochemical reaction is the continued effect of this absorption process together with the secondary chemical changes which may set up chains.

With this preliminary talk on the present knowledge of photochemical reactions I shall now proceed to apply it in the case of plant respiration.

Historical review:

The earlier work on this branch of the subject is very scanty. It was Borodin [7] who discovered an indirect relation between light and respiration. He found that the respiration activity of leafy twigs gradually decreases in darkness. Bonnier and Mangin [6] showed that light has a direct effect on the respiratory mechanism. If plants are placed alternatively in light and darkness a retarding influence of light is noticed. This has no relation to carbon assimilation, for this effect is noticed even in plants without chlorophyll.

Maximov [23] finds that the effect of light upon *Aspergillus niger* varies with the age of the culture as also with the nature of the nutrient medium. Day [9] found 3% to 4% more respiration for barley in diffuse daylight.

Spoehr [35] divides the light reactions into two classes direct and indirect. In the first, with which we are here concerned, light directly acts bringing about physico-chemical changes of certain physiologically important substances within the organism.

Warburg [38] finds that light has some photochemical effect on respiration. Working on yeast he finds that respiration is arrested by the presence of CO. But if a mixture of yeast and CO is exposed to light, respiration re-starts. This is due to the dissociation in light of the CO which is bound to the Fe of the respiratory ferment.

Recently, De Boer [10] working critically with fungi finds no effect of light on respiration. This, as subsequently discussed, may be due to the inability of the colourless fungi to absorb the necessary radiation. For, to cause a primary photochemical process to take place, light must be absorbed in the system.

It should also be pointed out, that it is not necessarily true, that chemical reaction must follow absorption. For instance if radiations of long wavelengths are absorbed the quantum of energy may be too small to effect a reaction. It is possible that colourless fungi either cannot absorb radiations or absorb such radiations as are incapable of producing any chemical reactions.

The problem of the effect of light on respiration has been investigated in our laboratory from five different angles, viz.:—

(1) The respiration of non-green but coloured leaves and flowers in light.
(2) The respiration of colourless organs, like roots, in light.
(3) The respiration of green leaves in light and the after effect.
(4) The effect of temperature and light upon respiration.
(5) And finally, in view of our knowledge of respiration in light, the study of the real assimilation rate of carbon. We shall discuss these one by one and then try to arrive at some definite conclusions.

The floating respiration :

Most plants, respiring in darkness, show a slow fall in their respiration rate, when brought from light to darkness. This unstable transitory phase is noticed only at the first phase of respiration and is called the 'floating' respiration by Blackman [4]; while the low steady rate of respiration reached after the floating part is the 'protoplasmic' respiration.

That starvation is definitely not responsible for the fall in the floating part of the respiration curve, is shown by Ranjan [29] for Mangifera and Eugenia leaves. The leaves of these plants possess enough food material in reserve to maintain a high rate of respiration for weeks.

Physiological starvation, however, which can be brought about by high temperature, due to the shifting of the starch ⇌ sugar balance so that the available sugar decreases, is well known, but the laboratory temperature of 35°C. at which the experiments were conducted was not higher than the temperature in the open in the tropics. Thus physiological starvation too cannot explain the fall in the respiration rate.

In the light of the subsequent results, herein described, one is forced to conclude that this fall in the respiration rate at the 'floating part' is due to the direct effect of the absence of solar radiations on plant respiration.

The respiration of non-green but coloured leaves and flowers:

Work on the colourless leaves of *Croton* by Ranjan [29] shows, that during the first phase of respiration in darkness a slow fall o the typical floating type is noticed. When these leaves were illuminated from a 1,000 W. lamp, kept at a distance of one foot, the respiration rate actually showed a distinct increase throughout the period that the leaf was in light (Fig. 2).

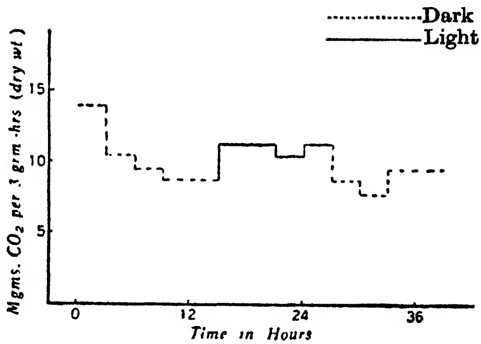


FIG. 2.

On removing the source of light the respiration rate fell off to assume the rate of respiration in darkness. The temperature all the while was kept steady, as the heat from the lamp was absorbed by a screen of flowing water interposed between the lamp and the plant material.

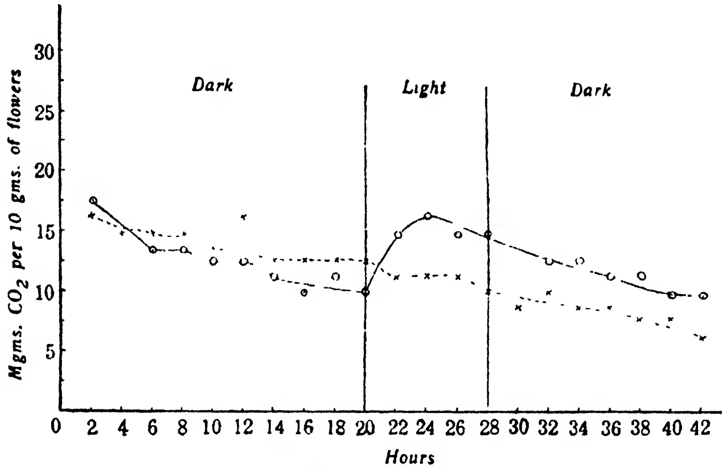
This rise in respiration can only be due to the catalyzing action of light. Further proof of this was furnished by the work on the coloured flowers.

It must be noted here, however, that most of the colourless leaves of *Croton* are not wholly devoid of colour but are faintly coloured yellow. Parija [27] and Saran's work confirm these results. Working on the albino varieties of *Aralia* they found that by exposing these plants even to a short period of diffused

light, the respiration rate after the exposure got augmented. It is quite probable that these albino varieties like the faintly yellow leaves of *Croton* contained some pigment.

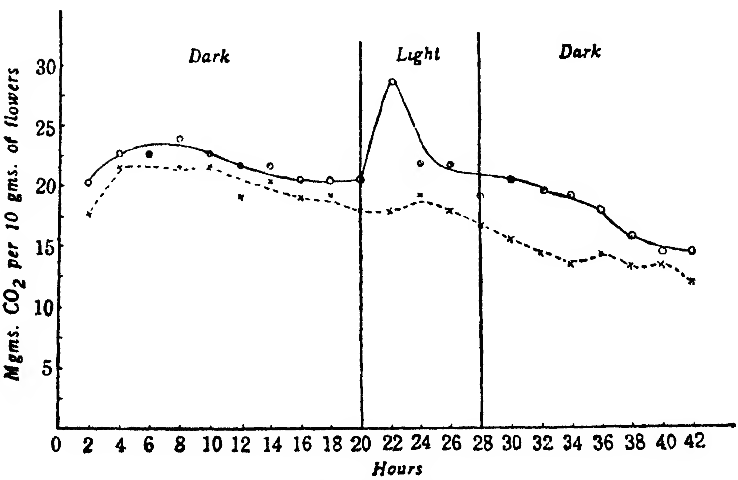
The rate of Respiration of some coloured flowers

Ranjan and Saxena [33] working on the inflorescences of *Bougainvillea*, (yellow and pink) *Nerium* flowers and yellow



(*Nerium*—pink)

Fig. 3.

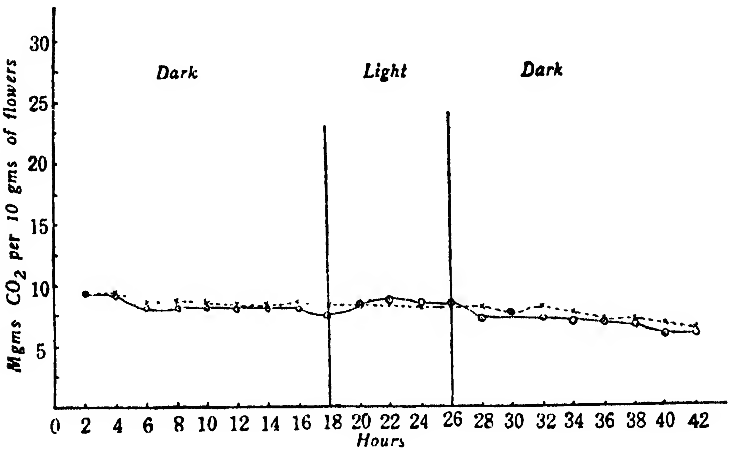


(*Bougainvillea*)

Fig. 4.

Canna flowers, found that the floating respiration in both *Bougainvillea* and *Nerium* showed the usual fall and when after about 18–20 hours' light was administered from a 1,500 W. Osram lamp kept at a distance of one foot, the respiration rate quickly went up. Once the high peak was reached, the respiration rate, however, slightly declined off even in light.

When the plants were brought back to darkness, the respiration rate steadily fell off. The respiration of *Canna* flowers, on the other hand, behaves somewhat differently to the respiration of *Nerium* or *Bougainvillea*. In *Canna*, Fig. 5, one notices a total absence of any fall in the 'floating' respiration while the increase in the respiration rate in light is only very slight. Thus there appears to be a certain co-relation, between the fall in the 'floating' respiration and a rise in the respiration when plants are exposed to light.



(*Canna*)

FIG. 5.

This fact leads us to suggest that if normally the floating respiration keeps low from the very start, then the subsequent exposure to light will bring about no change in the respiration rate.

The analysis of both the plastid and anthocyanin pigments of these flowers revealed that whereas in *Nerium* and *Bougainvillea* these pigments were in abundance, *Canna* flowers contained very little of them. If now, the solar energy of the right frequency is arrested by such pigments, then the carbohydrate molecules in *Nerium* and *Bougainvillea* will necessarily get activated and so bring about increased respiration. From the same viewpoint the respiration of *Canna*, which contained less of these pigments, will remain low in light.

In the cases of *Nerium* and *Bougainvillea*, there was a long continuous fall when the plants were brought from open sunshine to darkness in the laboratory and so also there was a long continuous fall after the laboratory illumination to darkness. (See figs. 3 and 4.) This feature is of considerable importance, for, while assuming that respiration in light is also a photochemical process, one will not be able to apply Einstein's law of photochemical equivalence. For, we have seen that even when light is cut off the reaction goes on at a relatively fast rate, though diminishing in its rate during successive hours. In-vitro experiments on photochemical reactions may give us some insight into this type of complicated reactions. For instance, in the case of chain reactions met with in certain types of photochemical actions the products of reactions liberate sufficient energy to activate additional reactants, causing a chain of reactions to take place. An illustration may serve to explain the point. In the formation of HCl from H_2 and Cl_2, the following chain reaction is supposed to take place.

$$
\begin{aligned}
Cl_2 + \text{light} &= 2Cl. \\
Cl + H_2 &= HCl + H. \\
H + Cl_2 &= HCl + Cl. \\
Cl + H_2 &= HCl + H. \quad \text{And so on.}
\end{aligned}
$$

As I have said before it is now well established that even in exothermal reactions the reacting molecules have to get excited before they can react and I cited the case of a ball which has to be pushed from a roof before it can fall and thus lose its energy. Now in the photochemical synthesis of HCl from H_2 and Cl_2, if q be the energy given out in the reaction and $h\nu$ is the energy which is necessary to activate the Cl_2 molecule, then in the reaction the energy given out will be $q-h\nu$. Obviously, this energy is greater than $h\nu$, and is, therefore, sufficient to activate a second molecule of chlorine, which on reacting will liberate again a sufficient quantity of energy to bring about a reaction of the third molecule.

If the energy is not dissipated away then once a reaction starts it will continue indefinitely. But the energy does get dissipated hence a gradual loss in the reaction rate. The slow fall in the rate of respiration when plants are brought from light to darkness, could also be explained on somewhat similar lines, viz. (1) the accelerated pace set up in light continues owing to chain reactions even in darkness, but (2) owing to other reactions in which catalysts are likely to play a part, the chain reactions break up and the respiration rate drops off.

The quick rise of the respiration rate and its subsequent slight fall even during the period of exposure to light is more difficult to explain and may be due to a variety of causes, amongst the foremost of them being the effect of light on (1) the permeability of the protoplasm, (2) the viscosity of the

protoplasm, (3) the plasma membrane, (4) the action on enzymes, or (5) the formation of internal filters.

In this short paper it is not possible to give full justice to the works of various investigators on these problems, but a few of the more important recent works will be dealt with.

Lepeschkin [22] using the pulvinus cells of *Phaseolus* and *Spirogyra* filaments concludes that light increases the permeability to KNO_3 with increased illumination. He used the isotonic coefficient method. Later Zycha [42] criticized this method and showed that Lepeschkin's results are unreliable. Hoffmann using the Hofler plasmometric method also finds an increase in permeability. Hoagland and Davis [18] measured directly the amount of anion accumulating in the sap of *Nitella* in darkness and in white light. They found that light accelerated the accumulation of the anions. These authors think that light causes a change in the metabolic process. On the whole, there is a preponderance of opinion in favour of the increase in permeability in light. If that were so, then the decrease of respiration in prolonged exposure to strong light may be ascribed to this phenomenon.

Moreover, light also affects the viscosity of the protoplasm as has been shown by Huber [20], Weber [39] and others. Weber noted the difference in the form of plasmolysis. Convex plasmolysis is associated with relativity low viscosity and concave with high viscosity. Leaves in darkness show 'convex' while leaves in light show concave plasmolysis. Hence he concludes that viscosity is higher in the light than in darkness.

Heilbrunn and Daugherty [17] have shown that ultraviolet light releases calcium from the cell cortex, which then enters the protoplasm proper causing first liquefaction and then gelation. Now, as it is supposed, if the plasma membrane of a cell is a calcium gel, then light radiations will weaken such a gel by the removal of the calcium and consequently the permeability will increase.

The action of radiations on the enzymatic system is yet imperfectly understood. Most of the work so far done has been with the extracts of enzymes, and that too in its impure form. So that it will be unsafe to draw definite conclusions from the results of experiments done in-vitro. But some in-vivo results are summarized below.

Green's [16] work upon the action of light upon diastase solution, and upon diastase of the leaf showed that bright sunlight had no effect.

Knott [21] found an increase in catalase activity of spinach after lengthening the photoperiod. Baly and Semmens [2] also report that when a strong beam of polarized light was made to fall upon the starch of potato, wheat, and corn, a rapid hydrolysis of starch to sugar occurred. On the other hand, Pincussen [28]

observed the destruction of diastase by light in the presence of oxygen.

Ranjan and Mallik [32] showed that an exposure of green leaves to light increases the hexose content and this formation of hexose is correlated with the increase of catalase activity.

It may, in this connection, be also mentioned that Chatterji [8] found that injection of alcohol in the leaves of *Eugenia jambolana* similarly increased both the hexose content and catalase activity.

Pal's [26] work shows that light may have considerable effect on the respiratory activity of fatty materials by changing the lipase activity and thereby altering the fatty acid—glycerol carbohydrate equilibrium. His work on Spirogyra [25] shows a profound effect of light on the metabolism of the algae in the conjugating stages probably due to some changes in the enzymic activities.

That the fall in the respiration rate of leaves, when exposed to prolonged period of illumination may be due to the formation of 'internal filter' is also possible. Oxygen may be one such filter. For during the exposure to light, carbon assimilation starts within the leaf and the consequent formation of oxygen takes place. It had been shown in in-vitro experiments that O_2 acts as a negative catalist. Its retarding influence on the photosynthesis of HCl has been noticed. Dhar finds that oxygen retards the reduction of mercuric chloride by potassium oxalate in the dark. And Allmand and Webb [1] have shown that the photolysis of potassium ferric oxalate practically stops on bubbling oxygen through the solution. Thus the slight fall in the respiratory rate may be due to some of these causes either acting singly or jointly, when leaves are subjected to prolonged exposure to light.

The Respiration Rate of Roots

I have said before that the respiration rate augments in light only in those cases where light energy of the right type is absorbed. This fact is further proved by experimentation on roots. For this work Pistia roots were chosen for the *Pistia* plant being a floating form, its roots are particularly suitable for experimental purposes. These roots, previous to their being put in the experimental chamber, were exposed to 2 hours of direct solar radiations.

Unlike the respiration rate of leaves the respiration here is a flat horizontal curve and shows no fall in the floating part (Fig. 6). The rate of its respiration was found to be about the same as the 'protoplasmic' respiration of its shoots per gram of the plant material. Previous exposure to light brought no change in the respiration rate. This explains two points: (1) the roots being colourless, light energy, which could cause activation of the molecules is not absorbed, and (2) the 'protoplasmic' respiration of green plants is the normal respiration in darkness.

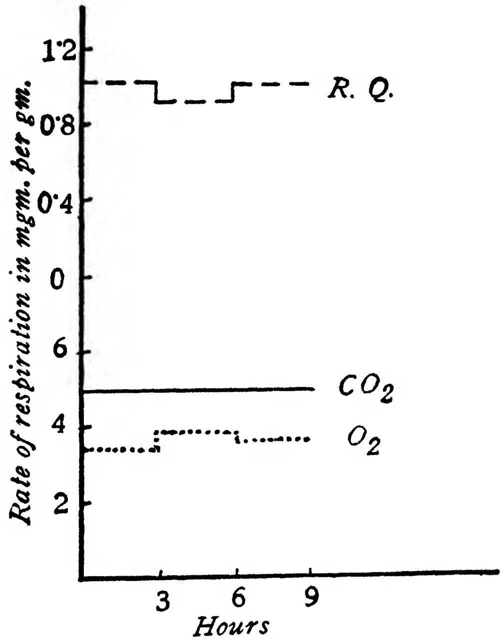


FIG. 6.

THE RESPIRATION RATE OF GREEN LEAVES IN LIGHT

From these considerations we now pass on to the respiration of green leaves in light. As is obvious, in light a green tissue will not show the emission of CO_2, for as soon as it is produced in respiration, its reduction to carbohydrates will take place and no CO_2 will escape out of the stomata. Thus it is only by indirect means that the respiration rate in light can be found.

The experiments on *Eugenia* leaves [29] show that when light from a 1,000 W. Osram lamp was given from a distance of one foot from the plant chamber, the CO_2 of respiration in the pettenkofer tubes rapidly declined off as the photosynthesis (Fig. 7) increased. After 15 hours of exposure the leaves were again darkened and the CO_2 in the pettenkofers went up.

During the period the leaves were in light, assimilation was going on and if even all the CO_2 of respiration was built back by assimilation—which of course is not the case—then at the end of light the rate of respiration should be the same as at the beginning of the illumination for the carbohydrates being the basic materials for respiration, their concentration should be the same at the end of light as at the beginning.

The 'after effect' of light, however, shows that the CO_2 emission gradually increases, hour by hour, to a value which is in excess of the respiration rate just prior to light exposure;

and soon after attaining a maximum value the respiration rate starts to fall off. Now, if we accept the hypothesis that the respiration is higher in light and that it gradually falls off in darkness, then the way to find out the respiration rate of a green leaf, in light, is to produce backwards the falling curve of respiration to the time at which light was switched off, i.e. to the time at which darkness began or to the zero hour of darkness. This has been drawn backwards in Fig. 7 marked A. The

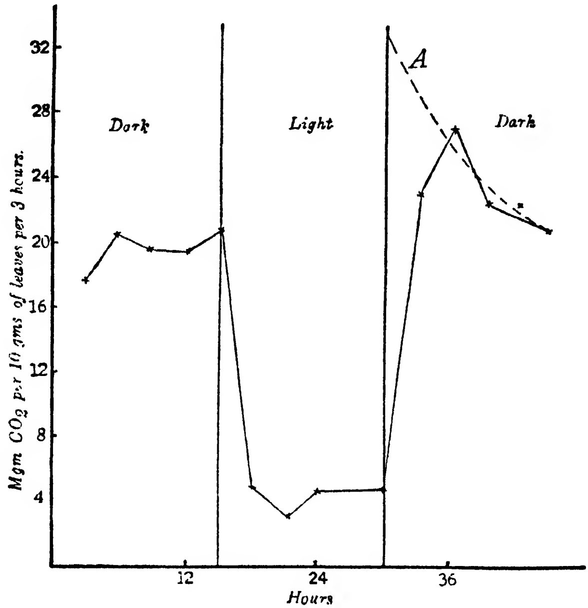


FIG. 7.

respiration rate, according to this hypothesis, is over 32 mg. CO_2 per 10 gm. of leaves per 3 hours in light but in darkness it falls off to about 20 mg. CO_2 per 3 hours. And the falling curve in-between these points (the floating respiration) is the 'after effect' caused by the primary photochemical process setting up 'chain reactions'. This thus accounts for the subsequent high rate of respiration for at least some time, even after the illumination is removed. That the 'after effect' may last for several hours, has also been shown in in-vitro experiments. In the case of mercury vapour it has been observed that the life period of the excited atom is of the order 10^{-6} sec. But recently Wood [41] has observed that if a mercury lamp is started and then switched off the glow persists for several seconds. In the case of solutions, Ghosh [15], Dhar [12] and others have shown that the 'after effect' has been found to exist for about 2 or more hours.

In the case of ferrous sulphate and iodine, Dhar and Mukerji [12] found the 'after effect' to last for 2 hours and 15 minutes, while in the case of the bleaching of dicyanin the 'after effect' continued for 4 hours and 10 minutes. It may be argued that this difference in the life period of the active molecules is due to the complex nature of the solvent molecules with which these authors have worked. I may, therefore, venture to suggest that the nature of the plant cells is more complex and naturally once they are activated the 'after effect' may last for a long period.

That the high peak of respiration is not reached all at once in experimentation is due to the numerous structural difficulties which impede the flow of CO_2 from the parenchyma cells of the leaf to the pettenkofer tubes. And by the time the new adjusted state can be arrived at, the respiration rate drops off hour by hour as the 'after effect' damps off in darkness.

Parija and Saran [27] have shown that light has no effect upon the respiration rate till after 40 hours in darkness. It is probable that for their leaves the first 40 hours are the period of floating respiration when the 'after effect' of light, due to the secondary photochemical reactions, is taking place. (Here the leaves were brought from light to the dark experimental condition of the laboratory.) And if during this period of 'after effect' light were to be administered it might not show any effect. It is only when the effect of light has died down, e.g. at the protoplasmic level, that the illumination will increase the respiration rate of leaves.

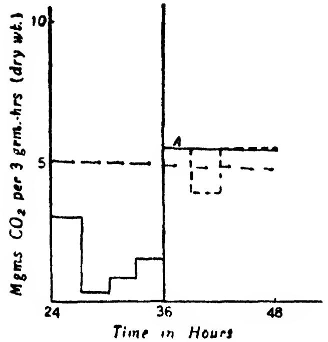
I shall now attempt to discuss a few records of experimentation on the influence of temperature on photochemical reactions in respiration.

The Temperature Effect upon Light Respiration

In-vitro experiments by various investigators have shown that generally speaking the temperature coefficient of a reaction occurring in light is much greater than unity but is smaller than that of the reaction in darkness. Dhar [11] finds in the case of the oxidation of potassium oxalate by iodine that in darkness for a 10°C. rise it has a value of 7·2 while in diffuse light the temperature coefficient is 3·4. This is due to the activation of most molecules in light and thus further activation with rise of temperature is relatively smaller.

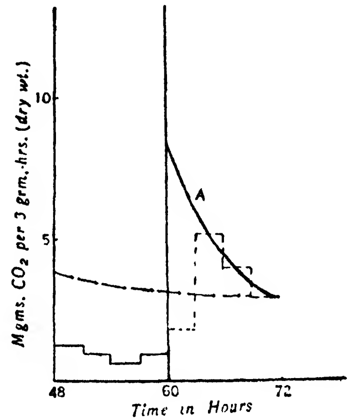
The work [30] on the temperature effect was done with the entire plants of *Pistia* which possesses a rosette of green leaves. The range of temperature varied from 20·5°C. to 40°C. Figs. 8–11 give the respiratory index of the plants in light and darkness at temperatures of 20·5°C., 27°C., 35°C. and 40°C. The arrowhead lines show the course of the protoplasmic respiration in darkness, and the continuous lines point out the low CO_2 emission as seen by titrations of the contents of pettenkofer

tubes due to the partial assimilation of the CO_2 given out in respiration in light. The dotted line shows the respiration rate in darkness after exposure to light.



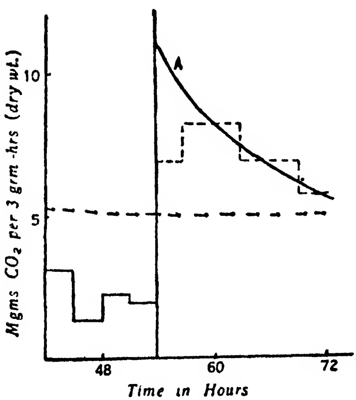
(Temp. 20·5°C.)

FIG. 8.



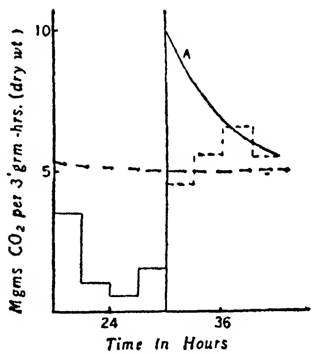
(Temp. 27°C.)

FIG. 9.



(Temp. 35°C.)

FIG. 10.



(Temp. 40°C.)

FIG. 11.

Following up our previous method, of studying the 'after effect' of light, to find out the respiration rate during the period the leaf was illuminated, one finds that the respiration rate gradually falls in darkness till its final particular temperature level is reached. The respiration curve is now drawn backwards to the zero hour. This is shown by curves marked A in Figs. 8–11.

I must confess here that these curves marked A are fairly arbitrary and can be subjected to certain amount of variations.

Nevertheless, they bring out forcibly the basic facts that differences in increased respiration in light do exist at varying temperatures. The zero hour levels show that at 40°C. the respiration rate in light was in the neighbourhood of 10 Mg. CO_2; and at 35°C. 11·1 Mg. CO_2; at 27°C. 8·5 Mg. CO_2; and at 20·5°C. only 5·5 Mg. CO_2.

It is important now to know the relative increase of the respiration rate in light over the respiration rate of leaves in darkness. The measurements of this rise in the respiration rate in light show that it is twice at 40°C. while at 35°C. it is 2·2 and at 27°C. it is as much as 2·5 times. While at 20·5°C. the increase is only about 1·1 times. We thus find that the maximum rise in the respiration rate in light is at 27°C. though the maximum intensity is at 35°C. This marked increase in both rise and intensity which we find within the limits of 27° and 35° decreases with higher temperatures. On the other hand, the relative increase is again very small at low temperatures.

Scheme of the Reactions and the Energy involved

We assume that in respiration, as in photosynthesis, there are at least two reactions: (1) the primary reaction and (2) the secondary reaction; the former is both thermal as also photochemical, while the latter is only thermal.

For convenience let us resolve these reactions in accordance with the following scheme:—

$$\underset{(1)}{A\text{—}B}\underset{(2)}{\text{—}C}$$

A—B is primary and B—C is secondary. The rate of B—C will depend upon the rate of A—B. In dark at 20°C. both A—B and B—C are slow and the rate of respiration is consequently slow. If now light is given A—B becomes accelerated while B—C remains slow. Thus the reaction here is limited by the rate of B—C which being thermal, the augmentation of respiration by light does not take place at this temperature. At 27°C. the rate of reaction B—C is capable of being faster than at 20°C. But the primary reaction A—B is not so much accelerated, for this reaction is also a photochemical one and not only a thermal process. Therefore, here the rate of reaction is not controlled by B—C but by A—B. Therefore, when light is given this primary reaction increases and as B—C is already in excess of the limiting value due to increased temperature, there is an increased respiratory rate. At 35°C. due to the primary reaction being thermal, to a certain extent, the reacting molecules are already in a greater excited state than they were at 27°C. But as there is a limit to the number of molecules which can be thus excited, the administration of light, although it does cause slightly greater excitation of molecules, cannot do

so beyond a certain limiting value. Thus even if there is a higher reaction rate, the relative increase in the respiration rate is less at 35°C. than at 27°C. The same holds good for respiration at 40°C. with this additional reason that at this temperature the time factor also becomes operative.

In Blackmán's scheme[4] the reserve carbohydrates break down to sugars and these then go into the activated forms with a higher energy content. This reaction causes activation which according to the scheme given above should correspond to the 'primary process'. In the 'secondary reaction' which is purely thermal, these activated forms break down, in glycolysis, to substances with half the number of carbon atoms. That enzymes and temperature play their respective rôles in these reactions is beyond question.

The following scheme is suggested:—

Hydrolysis.

$$\text{Carbohydrates} \longrightarrow n\ (\text{Glucose}).$$

Primary reaction.

$$2\ \text{glucose} + hv \longrightarrow \text{glucose}' + \text{glucose}.$$

Secondary rection.

$$\text{Glucose}' + \text{En} \longrightarrow 2C_3H_6O_3 + q.$$
$$2\ \text{glucose} + q \longrightarrow \text{glucose}' + \text{glucose}.$$
$$\text{Glucose}' + \text{En} \longrightarrow 2C_3H_6O_3 + q.$$

And so on.

N.B.—En = Enzyme.

$q = hv +$ the difference of the energy between $C_6H_{12}O_6$ and $C_3H_6O_3$.

Repurcussions of Light Respiration on Carbon Assimilation

We will now finally close this discussion with a consideration of the repurcussions of these results on our knowledge of carbon assimilation by green plants. As we all know in the study of carbon assimilation we first note the apparent assimilation rate and then add to this, the CO_2 of the respiration which gives us the real assimilation value. The CO_2 of respiration is usually taken by noting the respiration rate, just before and after light and the mean of the two gives the respiration rate during the period of assimilation. If now the respiration rate definitely increases in light and also, as has just been pointed out, this increase varies with temperature, the previous work done on the

rate of real assimilation becomes of rather doubtful value. Some work has been done in this laboratory by the writer[31] on the carbon assimilation of *Eugenia jambolana* leaves at varying temperatures. These results are summarized in Fig. 12 in which

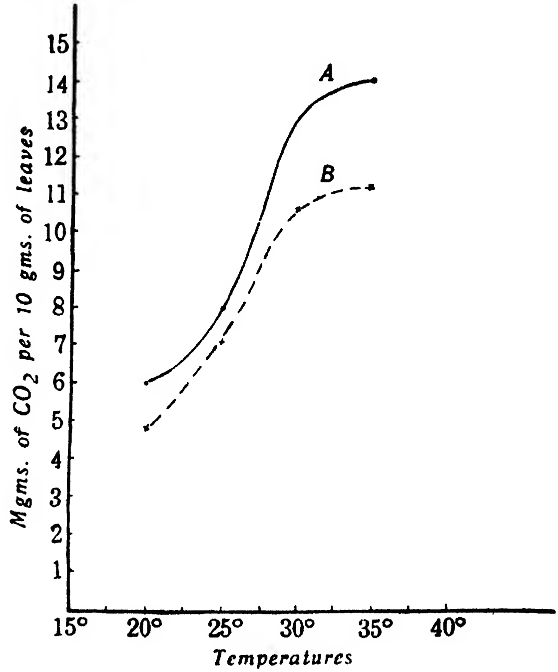


Fig. 12.

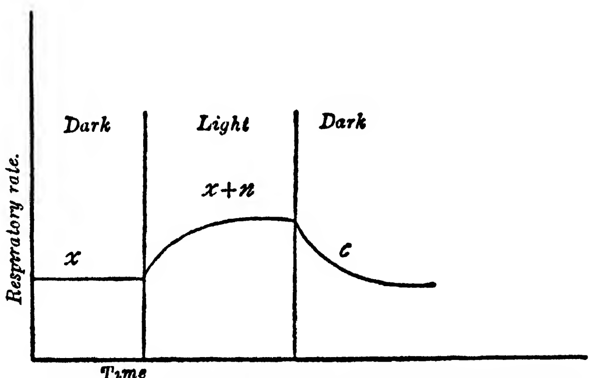
the curves of real assimilation (marked B) and the derived real photosynthesis values (marked A) at different temperatures are shown. The curve B shows a steady rise with increasing temperature up to 30°C.: beyond this temperature the rise, however, falls off and the curve tends to assume a horizontal course. On the other hand, the curve A follows an S-shaped course indicating a slow rise between 20°–25° and 30°–35°C.: between these two extremes the curve indicates a rapid acceleration. These results are consonant with the view that near about 20°C. the secondary thermal reaction is limiting the respiratory rate and as the dark reaction in photosynthesis, being thermal, also remains limiting then the Q_{10} values for assimilation between 20°–25°C. will be low. Between 25° and 30°C., however, the increase in the respiratory rate is at its maximum in light. This would seem to indicate that between these temperatures the relative increase in assimilation or the Q_{10} for assimilation would be the highest also. This is actually found to be the case, for the assimilation curve

shows a steep rise between 25°–30°C. Beyond these temperatures the Q_{10} for respiratory rate decreases and so also the Q_{10} for assimilation.

Conclusion

Ladies and gentlemen, we may, therefore, conclude that the green leaves and the beautiful flowers that one sees, not only colour for us all the world of vegetation and with their beauty fill our hearts with joy; but they also do something more. To quote Sir William Bragg they help the world to make the first step in the life process. The green pigment chlorophyll of the leaf, as we all know, is vital for building up of our food. But the orange yellow pigments, carotin and Xanthophyll which are found along with the chlorophyll of leaves and which give colour to many flowers, have also a certain definite rôle. Not only are they responsible for the formation of certain vitamins but they also serve the oxidative processes in the leaves and flowers by absorbing the blue-violet rays of the sun and transmitting the energy so absorbed to the reacting metabolites in these tissues.

The beautiful reds, purples, blues and yellows of many flowers and the reds of tender young leaves are due to the anthocyanin pigments. These too like the hydrocarbon pigments absorb the radiant energy and transmit it to the relatively slow oxidizing metabolites to rapidly increase their oxidizing power, so vital to the actively dividing cells of a young leaf or to the developing young embryo of a flower. The respiration rates in these cases will then follow a course shown graphically in Fig. 13.



Schematic sketch of the respiratory graph in light and dark.

FIG. 13.

Suppose the rate of the protoplasmic phase of respiration is x; now when light is given the respiratory rate of a green or coloured tissue increases gradually to $x+n$; then again when

darkness is restored there is a gradual fall till the curve assumes a constant level the value of which is again x. This part of the curve (as shown by c) is the exact replica of the graph obtained when the plant material is brought from light to the experimental conditions in dark; the gradually falling part, which we might say the 'after effect' of light, is comparable to the floating part of respiration in darkness and the level part to the protoplasmic phase.

The interaction of light and darkness on the activation of molecules and enzymes is best explained by the following scheme (Fig. 14).

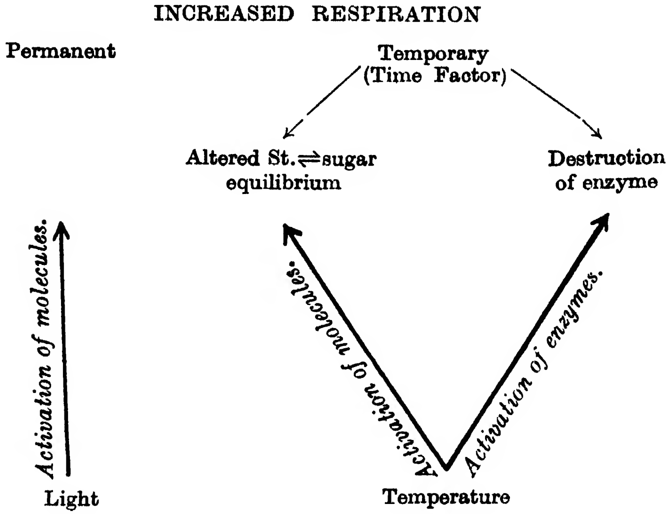


FIG. 14.

The increase of respiration by light is due in fact, to a large extent, to the activation of more of the reacting molecules in light than in dark at a given temperature. Although a very high temperature activates the molecules to a higher quantum state, it also destroys and renders inactive the enzymatic complex which attacks the activated molecules.

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SECTION OF ZOOLOGY

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Presidential Address

(*Delivered on Jan. 6, 1941*)

SOME ASPECTS OF MAMMALIAN PLACENTA

I thank you very much for the honour you have conferred on me by electing me this year as the President of the Zoology Section of the Indian Science Congress. I am aware of my limitations as a zoologist, for till very recently it was my privilege to teach Physiology to the students of the Medical College in Mysore. I confess I felt greatly embarrassed in choosing a topic to speak to you about. Since the last meeting of the Science Congress in Benares, Zoological Research in our country has assumed relatively vast proportions as is evidenced by the steady increase in the number of papers presented year after year before this section.

A perusal of the learned addresses of my predecessors has impressed upon me the variety of subjects open for serious thought, but at the same time, no hard and fast rule appears to have been laid down as to the choice of the subject. It has however been usual for the President to present in his address an account of some piece of his own research, or to summarize the progress of research in his subject. My first thought was to devote this opportunity to outline the significance of the study of that fascinating group of animals, viz., Lemuroidea, but on consideration I decided to review on this occasion some aspects of the Mammalian Placentation. There have appeared several illuminating monographs in which the phylogeny and morphology of the Placenta have been admirably discussed and to those interested in these aspects of the subject the lectures of Sir William Turner [1] and Robinson [2] and the monographs of Duval [3], Strahl, Jenkinson [4], Assheton [5], Grosser [6], Marshall [7], Hill [8] and Wislocki [9] would yield much information. The subject that has intrigued me is its nutritional function. It is essential to know, and indeed it is considered a good principle, to understand the precise meaning of the terms. I shall therefore attempt a brief answer, without going too deeply into its history, to the question 'What is Placenta?' Seventeenth century may be correctly described as a period

in which scientific enquiry became organized. Harvey[10] was the first to state that the placenta was an organ which elaborated from the maternal blood, the food required for the development and growth of the foetus. Mayow[11] considered that the placenta performed the functions of a *foetal lung*. John and William Hunter put forward the view that the maternal blood circulated through the placenta—a view that materially assists in appreciating the functions of the placenta. From the time of Harvey to that of Jenkinson our conception of placenta has undergone some little change and Jenkinson in his monograph on Vertebrate Embryology states that the placenta is that organ in which the blood vessels of the embryo are brought into intimate anatomical and physiological relation with the spaces—which may be blood vessels or lacunae of quite a different character —in which maternal blood is circulating. The teaching of Otto Grosser, with whom most students of Mammalian Embryology agree, is that placentation may be defined as the intimate junction of the mucosa of the uterus with the chorion for purposes of exchange of material between the mother and the offspring. Professor Hill has impressed on his students that the actual placenta is a composite structure being partly foetal and partly maternal. The two parts may be in simple apposition or intimately blended but in no case is there an admixture of foetal and maternal blood streams. The main functions of this structural relationship are undoubtedly those involving the supply of nutritive material and elimination of waste products. More recently Mossman has stated that 'the normal mammalian placenta is an apposition or fusion of the foetal membranes to the uterine mucosa for physiological exchange'. Mossman's definition of the term is at once brief and apt.

I shall now proceed to consider very briefly the morphology of the placenta. There are, as is well known, two types of placenta—the yolk-sac placentae and the allantoic placentae. The former, except in the native bear and the wombat, is usually of transitory functional significance. In the Eutherian mammals it is the allantoic placenta that is significant. Before the advent of high power microscopes and the microtome, the only method of classification was the one that could be done by naked eye examination. Accordingly, the placenta was said to be diffuse, multiplex, zonary, cotyledonary or discoidal according to its external appearance. This primitive classification, it is apparent, does not assist us clearly to understand either the structure or the significance of the different types. A slightly improved method of classifying the organ, based on the presumption that in certain forms there was loss of maternal tissue during parturition, was, as noted in the following table advanced by Weber, Huxley, and Strahl.

Weber.	Huxley.	Strahl.
(*a*) Caducous. (Maternal and foetal parts shed at birth.)	(*a*) Deciduate.	(*a*) Placenta Vera.
(*b*) Non-caducous.	(*b*) Non-deciduate.	(*b*) Semi placenta.

(It must be remembered that in some instances as in Huxley's contra-deciduate type, part of the placenta is retained in the uterus and finally autolyzed.)

Robinson's classification of the placenta into *Conjoined* and *Apposed* types, advocated in his Hunterian Lecture, made no great advance over the previous ones. Assheton[12] made use of the activity of trophoblast and classified the placenta into two types, viz., *Placenta Cumulate* and *Placenta plicate.* Even this division, much as it tended to explain some features in placental organization, must be held to be incomplete. The credit of establishing a system of classification, which has general approval and which constitutes a distinct advance over the binary systems, must be assigned to Otto Grosser[13]. Otto Grosser bases his classification on the exact relations of the maternal and foetal tissues. He recognized four types, characteristic features of which may now be summarized.

A. *Placenta epithelio-chorialis* type as exemplified by the placenta of the pig in which all maternal tissues are preserved, the foetal trophoblast being apposed to the uterine epithelium.

B. *Placenta syndesmo-chorialis.* In this type the uterine epithelium disappears to a large extent; and the trophoblastic epithelium is brought into contact with the maternal connective tissue as in the sheep.

C. *Placenta endothelio-chorialis* constitutes the third type in which, with the disappearance of the uterine epithelium and connective tissue, the foetal trophoblast comes into contact with the maternal capillaries as the carnivores.

D. *Placenta haemo-chorialis* type in which uterine epithelium, connective tissue and maternal capillary endothelium disappear with the result the maternal blood circulates in the lacunae formed by the trophoblast and bathes the trophoblast as in Rodentia, Insectivora, Cheiroptera, Anthropoid Apes and Man.

(Further subdivision of these main types exist, but it is unnecessary to go into details for purposes of this discussion.)

The histological study of the placenta of various groups has placed at our disposal a mass of facts which has enabled us to understand to some extent the functional significance of the relationship of the foetal and maternal tissues. The main object of the development of the Placenta is to ensure satisfactory performance of those physiological functions—supply of food, oxygen and elimination of carbon dioxide and other waste products, necessary for the growth of the embryo. In considering this aspect of the question, it is necessary to bear in mind, the now universally accepted fact that the foetal blood is always separated from the maternal blood stream. The nature of this separation differs widely in the different types of placenta. Thus in the epithelio-chorialis type the substances from the maternal blood have to pass through six different structures before they could get into the foetal blood. First the endothelium of the maternal capillary, the connective tissue around it, the uterine epithelium, the trophoblastic epithelium, the connective tissue of the allanto-chorion and the endothelium of the foetal capillary. In the Syndesmo-chorialis type, for the most part, the uterine epithelium is lacking and the materials have to pass through the existing five layers of cells. In the endothelial type, the trophoblast, as stated already, comes into intimate contact with the uterine capillaries and the barrier for the passage of substances is reduced to four layers, till at last in the haemo-chorial type with the disappearance of the walls of the maternal capillaries, the maternal blood bathes the trophoblast and the barrier is reduced to three layers of cells. In effect the thickness of the placental membrane varies in different animals.

It is obvious from the foregoing, that the exchange of material between the mother and foetus is conditioned by a variety of factors peculiar to each type of placenta. In its passage through the Fallopian tube, the fertilized ovum depends on the secretion of the surrounding tissues for its nourishment; and when it reaches the uterus, till it attaches itself to the uterine wall, and for some little time even after that, the growing embryo derives its nutrition from the secretion of the uterus. But with the establishment of the placenta, the nutrition of the embryo is effected by the direct absorption of the products of uterine mucous membrane directly by the trophoblast; and with the vascularization of the allanto-chorion, the foetal nutrition is by the transference of material from the maternal to the foetal blood. The normal requirements of the foetus comprise the proteins, carbohydrates, fat, water, salts and vitamins. It is a well-known fact that the digestive products entering the

blood stream of the mother are circulating in the blood. The fats particularly are on a different footing, since during absorption they are resynthesized and reach the blood through the medium of lymphatic vessels in an extremely fine state of division. Hence the mode of passage of proteins, carbohydrates and fats across the placental barrier differs. The proteins are transferred as amino-acids to the foetal blood; and indeed a large number of investigators have succeeded in noting the presence of amino-acids in the foetal blood. It may, however, be stated that our knowledge concerning the exact nature of amino-acids passing from the maternal to the foetal blood is, as yet, in an unsatisfactory state and research on maternal and foetal bloods of animals with different types of placenta would, I have no doubt, yield valuable information.

Concerning the supply of carbohydrates, it should be observed that the glycogen store of the mother is the chief source although the possibility of the conversion of other food material after absorption by the foetus must be borne in mind. The rate of absorption and utilization of carbohydrates by the mammalian embryo is known to some extent, but extended investigations on Primates other than Man would perhaps yield information of much value. I make this suggestion in view of the abundance of monkeys in India and the relative ease with which they may be obtained.

Information as regards the transport of fat from the maternal to foetal blood stream is far from satisfactory. In recent times our ideas as regards the mode of transport of fat have changed to some extent. The explanation that the leucocytes of the maternal placental part, loaded with fat, migrate into the foetal part to supply the necessary fat has been reinforced. It is now held, as a result of the investigations of Sinclair,[14] McConnel and Sinclair [15] on the placenta of the rat, of Bickenbach and Rupp [16] on that of the rabbit, and that of Boyd and Wilson [17] on the human placenta, that the fats may either pass directly across the placental barrier to the foetal blood, thence to the foetus by way of the umbilical veins, or that the maternal placenta may act as a secreting organ, taking up the fat from the maternal blood stream, and passing it on to the foetal blood with or without modification. Although one or the other of the views just now mentioned may represent actual state of affairs, it should be borne in mind that the enzymatic activity of the trophoblastic cells may also play an important part in the transfer of this material. Further, it has been observed that the fat content of the placenta decreases with age and an answer to the question whether the placenta acts as judicious regulator of fat supply to the growing embryo would assist in evaluating the function of the placenta. Here again is a problem which promises fruitful results.

Our knowledge of the nature of placental enzymes is meagre, and a well-planned study of the subject appears to me to be urgent and important. In view of the conflicting opinions that have been expressed as regards enzymes in the placenta, it is advisable to select for study, as Needham suggests, a placenta type which is readily separable into maternal and foetal parts, and to follow carefully the activity of any single enzyme throughout pregnancy.

The supply of vitamins to the growing embryo constitutes a very important factor in its normal development and attention may be drawn to lack of reliable information about the rôle of vitamins other than that of 'E'.

Except for the noteworthy contributions of Fenger on the placenta of the cow, not much is known about the mineral metabolism in the mammalian placenta.

I now proceed to consider the placenta as an organ of foetal respiration. The supply of oxygen to the fertilized ovum and elimination of carbon-dioxide may be said to be effected, till implantation, by the blood circulating in the Fallopian tube and uterus. It is only after vascularization of the allanto-chorion that the placenta begins to function as an organ of foetal respiration. It has been observed that the passages of two gases in opposite directions is determined by a variety of circumstances depending upon the nature of the placental structure. In any case, in normal development, respiration like nutrition is undoubtedly efficient in the species concerned. The problem whether the nature of blood, more particularly the nature of its haemoglobin, has any influence on respiratory activity needs consideration. It is universally known that haemoglobin has the power of carrying oxygen, as also carbon-dioxide in an easily dissociable state. Although in the normal gravid animal foetal respiration is efficiently carried out, both the quantity of oxygen needed and the rate of exchange of gases differ in different groups of animals. The recent researches of Barcroft and his collaborators have demonstrated that the foetal haemoglobin differs from that of the mother in the few animals that have been studied. Before any answer can be suggested to the question whether the structure of the placenta is in any way affected by the nature of the foetal haemoglobin, much more exhaustive enquiry with reference to a wide range of mammals is needed. It is, however, interesting to observe, in this connection, that the studies of Boor and Hektoen indicate that the carbon monoxide haemoglobin from different mammals is species specific. Further, it has been observed that there are noticeable differences in the property of the blood of different animals and such differences may be due to specific differences—both qualitative and quantitative in their haemoglobins. Thus it may be assumed that respiratory functions of the placenta are varied in different species of mammals. It may perhaps not

be illogical to assume that the metabolic needs of the developing embryo in different species of mammals vary and the oxygen requirements accordingly differ. Hence it is reasonable to state that the placental barrier, in each species, for the passage of oxygen and carbon-dioxide develops so as to meet the demands of the growing embryo. It has been noted above that in Grosser's classification of the placenta, the thickness of the placental membrane and the cellular constituents thereof differ. The membrane permits the passage of both the nutritive materials and respiratory gases. This phenomenon can only be attributed to the few special qualities of the living membrane, conditioned by the chemico-physical characteristics of both the maternal and foetal blood streams. The problem that waits satisfactory solution appears to me to be the physico-chemical properties of the placental barrier in different groups of animals with reference to the rate and intensity of exchange of materials.

Many zoologists (Hill, Grosser, etc.) whose inclination has been to study the structure of the placenta have maintained that the epithelio-chorialis type is primitive and that the haemo-chorialis type is very highly specialized. There are others (Wislocki, Mossman and others) who have strongly supported the view that the haemo-chorial type is the primitive organ and that all other types are secondarily derived. Convincing arguments may be adduced in favour of either view, but an unbiassed analysis of available data tends to support the former view. It is, however, not my object to discuss the phylogeny of the placenta but consider it only as an organ of foetal nutrition. It may not be unreasonable to assume that the urgency of the metabolic needs of the growing embryo determines the structure of the organ of foetal nutrition. The adequacy of foetal nutrition may be said to determine the normal development of the foetus. The metabolism of the pregnant mother who has to supply the energy needs of the additional living protoplasmic tissue as represented by the growing embryo, becomes affected. It is no doubt true that a vast amount of information regarding nutritional requirements of the pregnant mother is available; yet it can by no means be stated to be complete. This subject opens up a fruitful field for future research. I hope I shall not be considered a trespasser if I were to entertain the hope that in the newly established ante-natal clinics in Indian Maternity Hospitals, the subject of nutrition of the pregnant mother will form the subject of serious research.

The studies of Physiologists, Biochemists and specialist medical men have tended to prove that efficient nutrition exercises an enormous influence on the general welfare of the animal and indirectly on the quality of the germ cells which are formed afresh throughout the greater part of life. Thus it may be inferred that the characteristics of the progeny would perhaps in the long run be improved. It has now become the

concern of Progressive Governments to enquire into the nutritional needs of live-stock and man. With this end in view Nutritional Research Laboratories have been established. Work of national importance has been turned out in these laboratories and it may be hoped that attention would also be directed to a study of foetal nutrition.

Even a rapid glance through the Records of the Indian Museum, *Journal of the Bombay Natural History*, *Journal of the Royal Asiatic Society of Bengal*, and the publications of learned bodies such as the National Institute of Sciences, National Academy of Sciences and the Indian Academy of Science, and the journals published by some of the Indian Universities convinces one that a vast amount of original work in Zoology has been done in India but equally impressive is the fact that the work is mostly morphological in its widest sense. Morphological studies, however essential and useful, it seems to me, must be made more dynamic. Zoologists have already rendered great service by their study of the microscopic anatomy of the placenta and by their interpretation about the functions of the structural units. Thanks largely to the recent researches of physiologists and biochemists, much useful information regarding foetal nutrition is available. There are, as the literature on the subject reveals, many aspects of the problem, and some of which I have already referred to, about which our knowledge is incomplete and our ignorance immense. Here in India as in the other more advanced western countries, adoption by zoologists of experimental methods in their investigation, I feel confident, would result in more valuable contributions.

In conclusion, I venture to plead for a co-operative effort by the zoologists, physiologists, specialist medical men and biochemists in a well-planned study of foetal nutrition.

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SECTION OF ENTOMOLOGY

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Presidential Address

(*Delivered on Jan. 6, 1941*)

SOME OBSERVATIONS ON THE PERIODICITY OF LOCUST INVASIONS IN INDIA

CONTENTS

INTRODUCTORY

My foremost duty is to express to all of you my deep appreciation of the great honour you have done me in electing me to preside over the sessions of the Entomology Section. I regrét, however, to say that I feel conscious that I have not been able, on account of various unfortunate circumstances, to do full justice to my duties in this respect.

Having been engaged during the last ten years of my life in work connected with locust investigations, it should not be altogether surprising to you to find that I have succumbed to the temptation of speaking to you today on the subject of locusts in India, the more so because locust swarms have reappeared this autumn after an absence of over eight years, and I trust that you would kindly bear with me if you find it rather uninteresting.

Locusts have been of perennial interest to man from time immemorial, especially in tropical and sub-tropical climates. To the primitive man, the sudden appearance of hordes of these creatures in huge clouds hiding the face of the earth from the sun and filling the air with a mysterious rustle, should have often

proved a source of fright. One might imagine him looking helplessly on their descent on the vegetation roundabout and their destruction perhaps of his small patch of grain, though he might be expected to indemnify himself by collecting handfuls of them for his own consumption.

In Biblical times (*circa* 1500 B.C.), they are reputed to have functioned as one of the plagues of Egypt, and since there are references in Sanskrit literature of the early centuries of the Christian era to locusts as one of the great menaces of the cultivator, there is little to doubt that locust invasions had formed as much a feature of life in the olden days as they do at the present time.

In Europe, information regarding the occurrence of past locust infestations collected from various records and chronicles dates back to the 15th century, but in India, where historical records are generally lacking, there are no reliable data regarding locusts except for casual references to their depredations in conjunction with famines, till the beginning of the nineteenth century. Cotes (1891) in his admirable report of the locust invasion of 1889-1890 in northern India has collected together most of the available information from the beginning of the 19th century, and from data drawn from these and other sources, outbreaks of the desert locust would appear to have occurred in India in the years 1803, 1810–12, 1821, 1834, 1845 and 1860–66. It was, however, from the year 1869 that fairly detailed information regarding infestations is available, and locust swarms are known to have prevailed in the following periods:—1869–1872, 1876–1881, 1889–1898, 1901–1907, 1912–1919 and 1926–1931.

The depredation caused by locusts during the last cycle of infestation is possibly still green in the memory of the agriculturists of North India, and it was at its worst during the years 1929 and 1930, when the swarms spread almost all over the country. The situation created by the extensive damage done by hopper bands and flier swarms in the summer-autumn months of 1929 was so acute that resolutions were passed at meetings held in December 1929 of the Advisory Board of the Imperial Council of Agricultural Research and the Board of Agriculture in India recommending to the Government of India that instant steps might be taken, *inter alia*, towards the formation of a central locust bureau for collecting and disseminating intelligence on locust movements and the institution of a comprehensive scheme of locust research for the investigation of the best methods of control, for working out the bionomics of the locust and for surveying the desert areas in search of the permanent breeding grounds of the locust within Indian limits. Ultimately, funds were sanctioned by the General Body of the Imperial Council of Agricultural Research for these purposes, and an elaborate scheme of locust research was set on foot in December 1930 which continued to operate till 31st March 1939.

AN EVENTFUL DECADE OF LOCUST RESEARCH

The last cycle of locust infestation affected not only India and the neighbouring countries of Baluchistan, Iran, Afghanistan and east Arabia, but also all parts of northern and central Africa and south-western Asia and led to various schemes of investigation being undertaken by their respective Administrations, particularly by the British and French Governments. The African area was attacked not only by the Desert Locust, but by two other locusts also, viz. the Tropical Migratory Locust (*Locusta migratoria migratoriodes* R. & F.) and the Red Locust (*Nomadacris septemfasciata* Serv.), besides which South Africa was also affected by the Brown Locust (*Locustana pardalina* Wlk.), which is fortunately peculiar to it.

The locust investigations carried out in the African areas have led to fairly remarkable results. In the case of the Tropical Migratory Locust, which spread over the greater part of the African Continent, covering altogether a huge expanse of over 10 million square miles, within a period of ten years, it was determined that the outbreak had originated in 1926-27 from a comparatively small area in the region of the Niger Bend in French Sudan, and, doubtless, the whole infestation might have been nipped in the bud, if the original outbreak centre had been controlled in time. Even in the case of the Red Locust, which has been active in Central and South Africa during the last ten years, the outbreak centres have been found to be confined to certain restricted areas, which it should be possible to keep under surveillance in order to prevent future outbreaks.

So far as the Desert Locust is concerned, the outbreak centres have been found to be situated partly along the coastal areas of Africa, Arabia and Baluchistan and partly in the interior, as in Rajputāna and Sudan. Further investigations are apparently necessary to definitely delimit the extent of the outbreak areas, especially in western Africa and Arabia, before they can be properly supervised.

As flying swarms are often capable of covering long distances and as evidently they do not respect international boundaries, it was found essential to arrange for a system of rapid exchange of reliable information in regard to the movements of swarms, between adjacent countries. It was also felt that an exchange of notes between affected countries on their experience in regard to various aspects of locust research and locust control, would be of mutual advantage. With this end in view, the first International Locust Conference was held at Rome under the auspices of the Italian Government in October 1931, in which various countries including Italy, Great Britain, France and Egypt participated. The second International Locust Conference was held at Paris in July 1932, the third, in which I had the honour to participate as a delegate from India, at London in September

1934, the fourth, in which Khan Bahadur M. Afzal Husain represented India, in April 1936, and the fifth at Brussels in August 1938. In the last two conferences over twenty governments were represented including the United States, Canada, Argentina and other countries of the New World.

In the course of the deliberations of these conferences, various aspects of locust research were thoroughly discussed. Results presented by workers in different countries were examined and a concerted scheme of locust research was formulated, which was incorporated in a series of resolutions. The latter were circulated to the governments concerned for favour of acceptance and for taking such action as might be considered possible. Besides providing opportunities for formal discussions, these conferences made it possible for workers to get into informal touch with one another and exchange mutual experiences.

Among some of the important results of the last conference at Brussels were resolutions recommending the setting up of international organizations for the preventive control of locust outbreak centres in Africa and western Asia in respect of the important locusts of the Old World. So far as India is concerned, the creation of the Locust Warning Organization by the Government of India might be expected to serve the purpose of watching developments in the outbreak areas, but it is doubtful if it would serve any useful purpose unless it is also equipped for dealing with outbreaks as they arise. Moreover, it is not known if the authorities in Iran have consented to co-operate with the Indian organization in dealing with outbreak centres in the Iran area. Since swarms have recently reappeared in India and we are probably on the threshold of a new locust cycle, the matter is in need of further attention.

On the whole, a great deal of new ground has been broken during the last decade. The studies carried out on various species of locusts in the countries affected have greatly enriched our knowledge of the habits and bionomics of locusts in general, as well as of the ways in which they react to their environment. A large volume of evidence has accumulated on the subject of phase transformation in nature, and much clarification has been obtained in regard to the manner in which initial outbreaks are brought into being, as a result of intensive ecological studies of the natural haunts of locusts. Detailed studies of the movements of swarms since 1926 by the International Locust Centre at London have shown clearly how infestations have been developing from year to year in the affected areas, and have also elucidated the general laws by which swarm movements are governed. A great deal of progress has also been achieved in the correlation of swarm movements with meteorological data. Much light has been thrown on the life-habits and activities of the solitary phase of various locusts, and the recognition of the ability of the solitaries to make long distance migrations, similar to those

of swarms, may be said to mark a milestone in the progress of locust research.

Some of the Important Locusts of the World

In the broadest sense of the word, a 'locust' is a grasshopper that is capable of appearing in large swarms and causing damage to crops. While there is little difference in general appearance and structure, the *grasshopper* lives a solitary life scattered in small numbers all over the area, whereas the *locust* tends to congregate together both in the younger stages as hopper bands and in the adult condition as flying swarms.

There are several species of locusts in the world, which are not only restricted in their distribution being confined to particular countries and to particular types of habitats, but also vastly differ from one another in their habits.

In the Old World, the most widely distributed species is the Migratory Locust (*Locusta migratoria* L.) which is itself sub-divided into distinct races:—(1) the European Locust—*Locusta migratoria* var. *rossica*, Uv. et Zol., adapted to a cold environment and found mostly in Europe and Siberia, (2) the Tropical Migratory Locust—*L. m. migratorioides* R. & F., found in most parts of tropical Africa, (3) the Malagasy Locust—*L. m. capito*, confined to the island of Madagascar, (4) the Chinese or Philippine Locust—*L.m. manilensis*, found in the Philippines and eastern Asia, and probably (5) the Indian Migratory Locust—usually found only in the solitary phase, which may possibly prove to be a different race.

Perhaps the best known is the locust of the Bible, the Desert Locust—*Schistocerca gregaria* Forsk., found in the desert or semi-desert regions of north Africa, south-west Asia and India. Other important locusts are: (1) the Red Locust of Central Africa—*Nomadacris septemfasciata* Serv., (2) the Brown Locust of South Africa—*Locustana pardalina* Wlk., (3) the Bombay Locust—*Patanga succincta* L., found in the Indian Peninsula and Malaya, (4) the Moroccan Locust—*Dociostaurus maroccanus* Thnbg., found in the hilly areas of north Africa, southern Europe and western and central Asia, and (5) the Italian Locust—*Calliptamus italicus* L., common in Europe and western Asia.

Besides these there are various species of grasshoppers in southern Russia and Siberia, which at times multiply and assume serious proportions.

In Australia, *Locusta migratoria* occurs sometimes in pest condition, but the really serious species are two indigenous grasshoppers—*Chortoicetes terminifera* Wlk., and *Austroicetes cruciata* Sauss., which swarm regularly once in two or three years in particular parts of that continent.

In the New World, the most prominent species is the South American Locust—*Schistocerca paranensis* Burm., whose distribution ranges from the Argentine in the south to Mexico in the north. It is found in varying numbers from year to year and is most destructive in Argentina. In North America, various species of *Melanoplus* have been found to appear in destructive numbers in the United States and Canada.

These locusts differ from one another not only in their general habits but also in the manner of their adjustment to their environment, some of them being evidently more advanced in their evolution as locusts than others.

Some species have only one generation in the year, as for example, the Bombay Locust, the Red Locust of Africa and the South American Locust, but they pass the greater part of the year in the adult stage, whereas other locusts—which also have a single annual generation—lead only a comparatively short life as adults, but lay eggs which lie quiescent in the soil throughout the autumn and winter, e.g. the Russian Migratory Locust, the Moroccan and the Italian Locusts, and the Australian *Austroicetes cruciata*.

The Desert Locust, on the other hand, is one that has normally two or more broods in the year, as also *Chortoicetes terminifera* of Australia and *Locusta migratoria migratorioides* of Africa.

The Bombay Locust is a species in which gregarious habits are manifested only in the adult stage, the hoppers being found distributed as scattered individuals among grass or crops. They have never been observed to form into bands. On the other hand, in other locusts, gregarious habits are generally observable both in the hopper and adult stages.

It is those species which possess the ability to pass through two or more generations in rapid succession during the same year that are most dangerous from the point of view of swarming. Given favourable conditions, such locusts are able to multiply very quickly in numbers, and when facilities for forming concentrations are also present, they attain the stage of incipient swarming extremely rapidly. The Desert Locust, the Tropical Migratory Locust, the Brown Locust and *Chortoicetes terminifera* belong to this category and all of them are capable of reaching the stage of mass-multiplication very quickly.

On the contrary, locusts having only a single generation in the year can increase numerically and maintain their numbers, only in the event of a succession of two or more good breeding seasons, and if a good watch is kept on their progressive development year by year, it should be possible to prognosticate the possibility of mass-multiplication early enough to enable the necessary precautionary measures being taken in time for their control.

PERIODICITY OF LOCUST OUTBREAKS

The destruction caused by locusts while an attack is in progress is, speaking generally, too well known to need any special description. Since, however, India has been, till quite recently, free from attack for nearly a decade, it is possibly difficult to appreciate its seriousness.

In years of good rainfall, large areas of land are sown and by autumn the heart of the cultivator is glad at the sight of fine crops promising a bountiful harvest. All at once, however, dark clouds appear and millions of locusts settle on his fields, and in the space of a night, the look of the area is changed. Where there had been smiling crops and green pastures only bare stalks and a huge litter of dung are seen, and the locusts are gone in search of fresh fields for destruction. At other times, the swarms do not care to feed; but what is infinitely worse, they lay millions of eggs in the field before they disappear, which would mean that in about a fortnight myriads of hoppers would emerge and marching from field to field carry wholesale destruction to the countryside.

When a locust outbreak begins, it may continue for a series of 3 to 5 years on the average, at the end of which the numbers of locusts would gradually diminish until the outbreak ultimately dies out. In certain species of locusts, however, the swarms never completely disappear, though there may be a perceptible diminution in numbers over an interval varying from 2 to 4 years, after which a gradual or sometimes a sudden rise may occur. Such a fluctuation in numbers may be due to various causes, but is most commonly due to variations in weather conditions in successive years.

In the case of a great many locusts, especially in regard to the African ones, little information is on record in regard to their occurrence in the past beyond the last 50 years. In Europe, on the other hand, data are available to indicate that the European Migratory Locust had been invading Central and Western Europe from the south or the south-east since the 15th century at fairly regular intervals. In Russia, where the fluctuations in the numbers of the locust have been closely studied, the general conclusion would appear to be that the main factor in the periodic increase in numbers is the occurrence of a succession of dry years.

Uichanco (1936) has collected a mass of data for the Eastern Migratory Locust in the Philippines dating from the 16th century, from which it is clear that the species has been occurring in destructive numbers at fairly regular intervals all over the Philippine region. But it is also seen that in the endemic areas situated in the southern parts, the swarms never disappear completely, and that the periods of mass-multiplication are

generally to be correlated with a succession of comparatively dry years.

In South America, the swarms of the Locust (*Schistocerca paranensis*) never completely cease to exist in the Argentine, but are subject to much fluctuation in numbers, a series of years of high multiplication being generally found to alternate with periods of comparatively small numbers of swarms.

In India, three species of locusts are present:—(1) the Migratory Locust, (2) the Bombay Locust, and (3) the Desert Locust. Of these, the Migratory Locust is generally found in its solitary phase all over India. There are indications, however, that it can occasionally assume gregarious habits and become a destructive pest. Cotes (1891—Indian Museum Notes) mentions about 'the Madras Locust Invasion of 1878' in a note on locusts, but is not definite about the species concerned. From an examination of the printed records in the files of the Development Department of the Madras Government, kindly lent to me for perusal, I have found clear proof that the locust concerned was the Migratory Locust. It would appear to have multiplied during the heavy rains of 1877 that followed the great South Indian drought of 1876, and to have spread from January 1878 onwards from the Tinnevelly District in the south gradually north and north-east as far as the Nellore District by the end of the year, after which it gradually died out. In 1937, again, a fairly heavy multiplication of this insect occurred in the Baluchistan, Rajputana, and Kathiawar areas of north-west India, but subsided by the end of the year. It is, therefore, necessary to keep this locust under observation in view of its potentialities for rapid multiplication under favourable conditions.

The Bombay Locust is endemic in the region of the Western Ghats and usually visits the neighbouring districts of the Bombay Presidency. In years of multiplication, its swarms invade Kathiawar, Central India, Central Provinces, Hyderabad, parts of Madras, and sometimes as far as the United Provinces, Bihar and Bengal. It is also known to be present in the Laccadive Islands. Buchanan (1807) has recorded the flight of a swarm in Mysore in the year 1800, and during the last century, swarms are known to have been present in 1835–1845, 1864–1866, 1878–1884, and 1901–1908. It is thus seen that it has been active only during comparatively short periods during the last century, but small swarms are known to have been seen also in certain years during the intervening periods. Since 1910 till the present time, however, no serious outbreak has occurred, and in the present imperfect state of our knowledge of its ecology and bionomics, it is difficult to account for its present quiescent condition.

The locust *par excellence* of India, whether judged by the frequency of its visitations or by the extent of its attacks, is the Desert Locust though it is the northern parts of India that are

mostly subject to its ravages. It is usually found in the desert regions of north-west India, but in years of mass-multiplication may invade many other parts of India, up to Assam in the east, and right up to the northern districts of Madras in the south. As this species has been the subject of special investigations in India since December 1930, much information has been gathered in regard to its prevalence in India in the past since the beginning of the last century, from which it is possible to make some observations on its periodicity.

Periodicity of the Desert Locust in India

Data on the occurrence of locusts in India up to 1870 have been gathered from Cotes' Report on the North-west Locust and from various provincial gazetteers and are decidedly scrappy, but from about the year 1870, when season and crop reports began to be published in various provinces, definite information as to the occurrence of swarms is obtainable.

Period 1800 to 1860

Cycle.	Year of occurrence.	Provinces affected.
I Cycle ..	1803	Infestation in Cutch.
II Cycle ..	1810-1813	Swarms in Kathiawar, Rajputana and Bengal.
III Cycle ..	1821	Swarm breeding at Etawah in U.P.
	1826	Locusts in Kathiawar.
IV Cycle ..	1833-34	Swarms in Kathiawar, Cutch and Rewa Kantha.
V Cycle ..	1843	Breeding in Rawalpindi.
	1845	Swarms in Panchmahals.

No information about locusts in India between 1845 and 1860, but locust swarms are known to have prevailed in 1855 in Egypt.

From the table on page 10 it is seen that there have been roughly about seven locust cycles, lasting 5 to 9 years each, from the year 1860. When locusts appear, they are seen at the same time in many parts of India, either breeding or migrating, the extent of spread being considerably greater in years of high

Period 1860 to 1940

Cycle Period.	Years of infestation in India.			Years of infestation outside India.					
	Baluchistan and N.W. India.	Cutch, etc.	Eastern India.	Iran.	Palestine.	Egypt.	Arabia, Red Sea.	Algeria.	Kenya.
(1) 1860–1866 ..	1860–62—Sind, Rajputana. 1863—all over.	1860–62 Cutch.	1862 (Monghyr)	..	1865	..	..	1864–66	..
I. Interval in India: 1867-1868 (2 years).									
(2) 1869–1873 ..	1869—All over N.W. India and Cutch 1870 and 1872—Punjab and Rajputana.			1872 (Baln.)	..	1869	1869	..	..
II. Interval in India: 1874-1875 (2 years).									
(3) 1876–1881 ..	All over north-western India.			1876 (Jask) 1881	1878	..	..	1876–78	..
III. Interval in India: 1882–1888 (7 years).									
(4) 1889–1898 ..	All over North India. Swarms reached the south in 1890.			1890, 1897, 1899	1890–92, 1899	1890	1889, 1890	1890–93	1898
IV. Interval in India: 1899 (1 year).									
(5) 1900–1907 ..	All over northern India.			1901–03	1902, 1904, 1908	1903-04	..	..	1901–09
V. Interval in India: 1908–1911 (4 years).									
(6) 1912–1919 ..	All over the north.			1913–16	1915	1914–16	..	..	1914–16, 1919
VI. Interval in India: 1920–1925 (6 years).									
(7) 1926–1931 ..	All over northern India: Reached the south in 1930.			1927–31	1928-29	1928–30	1928–30	1927–31	1928–30
VII. Interval in India: 1932–1939 (8 years).									

multiplication than in those in which only light breeding has occurred. On the other hand, during the intervals between locust cycles, few locusts are noticeable anywhere in India. The swarm-free intervals appear to have been usually short, but in three cases, namely, 1882–1888, 1920–1925 and the last one 1932–1939, they have been fairly long.

During the continuance of an outbreak, the activities of locusts are easily noted and reported, as they always move about in the form of large swarms. On the other hand, during the swarm-free periods, the presence of locusts cannot be easily detected, as they exist then, if at all, only in the form of individuals. All past records have reference, therefore, only to swarms noticed during years of locust incidence, and the information regarding swarm-free intervals is mostly an absolute blank.

During the recent swarm-free period—1932–1939—investigations were in progress under the scheme of locust research financed by the Imperial Council of Agricultural Research, in the course of which particular attention was paid to a study of the habits, ecology and distribution of the non-gregarious locusts found in the desert areas in greater or smaller numbers. Close observations made during this period have shown that, far from disappearing from the Indian area, the desert locust has been existing in the desert areas of Sind, Baluchistan and Rajputana, distributed among the scanty vegetation as scattered individuals mostly in the solitary phase. Continued watch on its movements and activities in all parts of its habitat has shown that it reacts to changes in the environment exactly in the same way as the *gregaria* phase locust. Its breeding is similarly dependent on favourable rainfall, and it migrates over long distances at the change of the seasons from one rainbelt to another, and goes through at least two generations in a year, one in winter-rain areas and the other in summer-rain areas. The main difference would appear to lie in the crowded life lived by the *gregaria* locust and in the high intensification of its activities under the influence of mass psychology. In the present state of our knowledge, the change in status of an apparently innocuous, obscure and sparsely distributed resident of the desert into a highly dreaded pest capable of appearing in vast hordes and dealing whole-sale destruction to crops, would appear to be due mostly to its reaction to a complex of meteorological factors favouring its breeding under crowded conditions.

Another fact of great significance is the circumstance that, whenever the desert locust assumes pest conditions, its swarms appear not only in the Indian area, but generally also in other regions subject to its incidence. During the last cycle, its swarms were active not only in India, but also over Iran, Iraq, Arabia, Egypt, Palestine, Algeria, Morocco, Sudan, and French West Africa. A more or less similar occurrence was observed during the earlier cycles: 1912–1919, 1900–1907, 1889–1898,

1876–1881 and 1869–1873. This possibly indicates the existence of certain common factors in this vast area, which conduce to the appearance of swarms almost simultaneously all over this area. In all possibility, this may be attributed to a general similarity of physical conditions met with over most of the region subject to its incidence, partly owing to the fact that it is part of a great semi-arid zone extending from the west coast of Africa to Central Asia, and partly because each of the three zones of locust habitat of this great area is composed in part of a belt coming under the influence of winter depressions and in part of another falling under the regime of the summer monsoons.

The General Course of a Locust Cycle in India

A fair amount of information is on record regarding the duration of the different outbreaks, the damage caused and the extent covered by the invasions since 1869, but it is only during the last cycle (1926–31), and especially during the years 1929 to 1931, that fairly detailed data have been available for examination. As a result, it has been possible to make a fairly close study of the various factors that were operative (1) in bringing this outbreak into being, (2) in contributing to its progress during the different seasons from year to year, and (3) in bringing about its eventual breakdown. The results of this study have, moreover, served to give a clue to the correct interpretation of the incomplete data available for the earlier visitations.

At the time of the last locust outbreak, there was no definite information available as to where the locust swarms came from, what direction they generally pursued, or what ultimately happened to them. The view commonly held was that most of the swarms were derived from a western source beyond the limits of India and that they generally pursued an eastward direction in the Indian area, where they ultimately died down after a few seasons of breeding.

A close study of the data of swarm movements gathered during the last visitation has served to give us a fair idea of the general activities of swarms in the course of a locust cycle. The general sequence of events during a year of locust swarm activity may be roughly classified under (1) over-wintering, (2) spring breeding, and (3) summer breeding.

Over-wintering: During the winter months, swarms are usually inactive and the locusts generally pass the cold weather scattered among the vegetation. When, however, any warm spells occur during winter, the swarms may make short migration flights from place to place.

Usually very few locust swarms remain in the desert areas of Rajputana, though in years of heavy or late breeding, some over-wintering may occur. The usual areas of over-wintering

are situated in southern Mekran and Lasbela, and in parts of Sind and Kachhi, and sometimes in southern Punjab.

Spring Breeding: With the reappearance of warm weather, swarms become active once again. If good rainfall occurs in January, locusts attain sexual maturity early, and may begin to lay eggs in the areas of over-wintering in February. In any case, swarms begin to migrate north up the hill-valleys as the season warms up, and may lay eggs wherever conditions are favourable during March and April.

In the Baluchistan area, swarms migrating north and north-east from the coastal plains of British and Iranian Mekran reach Kharan and Chagai in March-April, and, by May, they may enter Shorawak and Kandahar in Afghanistan and Sarawan and Quetta-Pishin in the uplands of Baluchistan. Ultimately, the swarms may reach the Kurram and Dera Ismail Khan areas of the N.W. Frontier Province by the end of May or early June. Similarly locusts, over-wintered in Kachhi and north Sind may work their way in spring up the hill-valleys of Mula, Bolan, Nari and Harnai, to reach the upland districts of Sarawan, Quetta-Pishin and Loralai districts by April-May. In the Punjab, swarms migrate in spring from district to district and may lay eggs wherever the situation is favourable.

The adults of the spring brood are ready for flying from the southern areas of breeding by April, and from areas further north by May or June. As by May and June, the interior of Baluchistan and southern Iran becomes an area of severe summer drought, the adults of the new generation begin to leave the areas where they bred, and are gradually carried by the prevailing winds eastwards into the Punjab, Sind and Rajputana, which they reach during June-July in successive waves of migration.

The new generation produced in the breeding areas in the Punjab and western United Provinces also migrate in May-June, the prevailing west wind carrying them eastwards into Central India, Bihar and Bengal.

Summer Breeding: By the middle or end of June, the monsoon current begins to enter north-west India, and the prevalent winds on the Indo-Gangetic plains become easterly, so that gradually all the swarms reaching eastern India are gradually found shifting westwards into western United Provinces, the Punjab and Rajputana by July. With the fall of good rains, the swarms begin to deposit their eggs in these areas. If good rainfall should occur in August and September, these swarms may lay a second and even a third batch of eggs. Moreover, the first adults of the monsoon brood usually are ready to fly by the middle of August, and these locusts are also generally able to lay eggs by September-October in the event of good rainfall, from which the adults of the second generation would emerge by the end of October or early in November.

The monsoon usually withdraws from the plains of north-west India by the middle of September, following which the desert areas of Rajputana, and to a less degree the surrounding areas of Sind and Punjab, temporarily develop into areas of drought combined with high day-temperatures. Apparently, these conditions are disliked by locust swarms, which show a tendency to leave the Rajputana areas at this time. In September and the early part of October, south-west winds still prevail in the desert and may carry the swarms north or north-east into the Punjab and United Provinces, whence the general trend is towards south-east. By the middle of October, north-east winds begin to prevail in Rajputana and may carry the swarms southwards into Kathiawar and Cutch or westwards into Sind, Baluchistan or south-western Punjab.

It has been found that swarms flying eastwards into the United Provinces, Bihar, Bengal and Assam, and southwards into Kathiawar, Bombay, and Central Provinces, in the autumn and winter months are not able to reach areas, where spring breeding is possible. Usually, most of these swarms die out ultimately. On the other hand, swarms migrating westwards into Sind and Punjab eventually move on into Baluchistan and Iran, where they begin to breed with the fall of winter rains.

Causes of Breakdowns: From the above facts, it is evident that in the Indo-Iranian region of locust outbreaks, the possibility of infestation being carried to the following year is dependent mostly on the extent to which swarms produced in the eastern areas in summer are able to reach the winter-rain zone. In 1928 and 1930, for instance, the westward migration of swarms in autumn was negligible, and very little of over-wintering was noted in the areas of southern Mekran and Iran in the winter of 1928-29 and 1930-31. The observations made by Predtechensky (1935) in the Persian area indicate that the comparatively small number of swarms that reached the Indian and the Persian areas in the spring of 1929 and 1931 were largely derived from extra-Indian sources—mostly from the direction of Oman in east Arabia. If this contingent had not arrived it is possible that a breakdown might have occurred in 1929 and 1931.

Another very important cause of the breakdown of the infestation is a failure of, or at least a serious defect in, the seasonal rainfall, sometimes in areas of winter precipitation and sometimes in those of summer rainfall, leading to a considerable decrease in the numbers of locusts. When a failure of breeding occurs both in winter and in summer, the locust cycle would naturally come to a sudden close.

On the other hand, favourable rainfall would result in a conspicuous increase in the numbers of locusts. In the monsoon areas, fairly well-distributed rainfall during the months of July, August and September, will lead to prolonged breeding, including

the production of a fairly large second generation, so as to bring about a high multiplication of locusts and a widespread dispersal of swarms in the different parts of India. A similar breeding followed by high multiplication would also result if there should be well-distributed rainfall in the winter-rain areas.

History of the cycle of 1926–1931: Tracing the course of the last locust cycle, we find locust swarms suddenly appearing in 1926 after an absence of six years. The origin of this cycle will be considered at a later stage, but the chief factors in the production of the new cycle would appear to be high winter rainfall in Mekran followed by prolonged and heavy summer rainfall in the desert areas, leading to protracted breeding especially in the southern areas of the desert.

1927: In the winter of 1926-27, west-bound migration of swarms was greatly in evidence, and there was much over-wintering. Spring breeding was heavy in the Punjab and Baluchistan in 1937. Summer breeding occurred in the Punjab and in Rajputana, but was, on the whole, moderate. Westward migration in autumn led to heavy over-wintering in the Mekran areas.

1928: Following good rainfall, there was extensive spring breeding in Baluchistan. Heavy summer migration occurred, but the monsoon rainfall was not well distributed, summer breeding occurred only in parts of Rajputana and the Punjab, and was on the whole light. Little of west-bound migration was noticed in the autumn.

1929: In the winter of 1928-29, there was no over-wintering of swarms in Mekran or Kachhi. Some swarms derived from over-wintered concentrations in the southern coast of Iran and in Oman reached Mekran, Kharan and Chagai at the end of March and in April, but did not lay eggs in these areas as there was no rainfall. They passed on to Sarawan and Quetta-Pishin in May and laid eggs in large concentrations as good rainfall had occurred here in consequence of which very acute infestation resulted here in May-June. Other swarms passed on to Dera Ismail Khan and the Punjab areas in May, but there was little oviposition on account of defective rainfall. The new generation produced in the uplands of Baluchistan and Iran reached the Punjab, Sind, Rajputana and the United Provinces in July and August, and the heavy rainfall then received induced intensive multiplication in these areas.

In the autumn months, swarms migrated south-east into Central Provinces, south into Kathiawar and Gujarat, and west into Baluchistan. The westward movement was specially pronounced, and enormous swarms passed over Lasbela and Baluchistan in the direction of Iran, and masses of locusts are known to have been drowned in the sea along the Mekran coast.

1930: In the winter of 1929-30, heavy over-wintering occurred in Sind, Punjab, Kachhi and many parts of Baluchistan.

Good rainfall was received in January-February in Baluchistan and Punjab. Extensive breeding occurred in the Kech and Panjgur areas in February-March, and in other parts of Baluchistan in April-May. Heavy spring breeding also occurred in the Punjab and United Provinces.

The resulting swarms migrated from Baluchistan in April-May eastwards into Sind, Punjab and Rajputana, whereas the Punjab swarms entered Central India and Bihar. With the appearance of the monsoon rains, breeding was set on foot in the Punjab, United Provinces and Rajputana, but as there was little rain in August and September, breeding terminated early and most of the swarms migrated eastwards into Bihar, Bengal and Assam, and southwards into Gujarat, Bombay and Central Provinces, reaching as far south as Warangal in Hyderabad State. There was very little of west-bound flight in autumn.

1931: Over-wintering swarms were not found anywhere. No locusts were noticeable in the Indian area, until small swarms of Oman origin (according to Predtechensky—1935) began to appear in Chagai in April from the direction of Iran. These swarms bred to a slight extent in Chagai, Sarawan and Quetta-Pishin, and penetrated as far as Kurram in June. The spring generation from Baluchistan migrated into Sind, Punjab and Rajputana in June-July. Monsoon rainfall was, however, not well distributed, and there was comparatively little breeding except in central and southern Rajputana where heavy falls were received in August. Summer-bred swarms were, on the whole, few compared with previous years, and in autumn most of them became dispersed, some towards the east, others towards the south and the rest towards the west flying into Sind and Baluchistan.

In 1932, the winter rains proved a failure in Baluchistan, so that there was no spring breeding, and the summer migration was limited to a few small groups of pinkish individuals, which were noticed on the Mekran and Lasbela coasts and in Sind in June. No swarms appeared and the cycle of 1926–1931 came to a definite close.

We thus see that the continuation of the outbreak in the Indo-Iranian region from year to year during the period 1926–1931 was not a simple case of a succession of seasonal broods, but a complex matter in which several independent factors were concerned. The development of the infestation is dependent on a chain of events which are severally affected by the character of the winter and summer rainfall, the conditions of humidity and temperature and the timely prevalence of seasonal winds necessary for carrying the swarms from one rain-belt to another. If one link or other in this chain of events is broken, a partial or even a complete breakdown may result. In fact, in the spring of 1931, there were no over-wintering swarms either in British or in Iranian Mekran, and a complete breakdown might

have occurred if swarms from the Oman area had not come into Baluchistan in April. Ultimately, the cycle came to a close as the result of poor breeding in the monsoon areas in the summer of 1931 followed by a failure of winter rains in the Mekran area.

Origin of Locust Cycles in India

Although tolerably full information is on record as to the progress and development of the recent locust cycle year by year, there is no clear evidence to indicate how the cycle originated for the simple reason that interest was taken in the locust outbreak only after swarm flights had commenced in the autumn of 1926. It might have been possible to gather full information only if the desert breeding grounds of the locust had been kept under observation during the swarm-free period of 1920–1925. On the other hand, the interval that followed the last cycle was under continued observation by the staff of the locust research scheme of the Imperial Council of Agricultural Research and the results of the studies carried out by them have been found to be of much help in the interpretation of the scanty data collected for 1926. They have shown that in the intervals between locust outbreaks the desert locust reverts to its solitary phase and is found existing in the desert breeding grounds in small numbers in a non-gregarious condition. Except for the circumstance that it does not live a crowded life, the solitary locust has been found to react to changes in its environment in much the same way as the *gregaria* phase locust. It breeds similarly after rainfall and migrates with the change of the seasons, but with the difference that its activities are not so intense.

In a study of the ecology of the solitary phase, the main problem is to determine the conditions in which groups of solitary individuals become transformed into gregarious swarms capable of dealing destruction to cultivation. In the course of the period, 1932 to 1939, several instances of such a transformation of phase were detected in the Mekran area, mainly caused by locust individuals migrating from the coastal areas in spring and early summer and concentrating in suitable patches of cultivation in the interior valleys for purposes of feeding and egg-laying. Since eggs are generally laid under crowded conditions, the hoppers hatching therefrom tend to get crowded and form incipient hopper bands, which subsequently develop into the primary swarms of fliers. Such situations as these, where phase transformation is brought about, are termed 'outbreak centres'. In June-July 1935 specially important outbreak centres were observed to have developed in Mekran and to have been instrumental in great part in bringing about a widespread locust incursion into Sind, Rajputana and Baluchistan in July-August 1935. The forms of which this incursion was composed, included a large proportion of the *transiens* and *gregaria* phases, and it is

practically certain that in case fairly heavy rainfall had occurred during the months of August and September in the Rajputana desert areas, these migrants might have bred extensively and developed into true *gregaria* swarms.

In the light of the above observations, the origin of some of the past locust cycles may now be examined. Taking the most recent case first, the following observations may be made.

1940 Outbreak: Since the closure of the locust research scheme of the Imperial Council and the taking over of the work of locust surveys in the desert on a comparatively limited scale by the Locust Warning Organization under the control of the Imperial Entomologist, in April 1939, important locust developments would appear to have occurred, ultimately resulting in the recent reappearance of swarms after an interval of over eight years. From the data contained in the monthly reports of the Locust Warning Organization since April 1939 (for which I am indebted to the Imperial Entomologist), the following tentative hypothesis is presented as to the probable sequence of events that had brought the new outbreak into existence. The final conclusions would, of course, have to be based on fuller data, including details of the biometrical facies of the populations and further information about the distribution of rainfall.

The rainfall received in the winter-spring season of 1938-39 in Mekran was fairly heavy and prolonged, and apparently led to concentrated breeding in the interior of Mekran and Upper Baluchistan including Kachhi during April-June 1939, but as the initial migrant population in the winter of 1938-39 on the coastal areas was very low, the multiplication was apparently not high enough to function as outbreak centres. The monsoon rainfall in the desert areas was more or less a failure except in the northern areas, where light breeding occurred, and the locusts bred here entirely migrated out of the desert by December.

The winter rainfall of 1939-40 in Mekran was moderate and the light population found at the end of winter in Mekran bred first on the coastal roks and at a later stage in the interior, but not to such an extent as to cause outbreak centres to form. In June, however, a light pink swarm was, according to an unconfirmed report, seen near the Iran borders in the Panjgur area—rather significant if correct. Summer migrants were first noticed in the Rajputana desert areas in June. The monsoon began early in the month of June, but the rains were not general but fell in scattered though fairly heavy showers. Owing to the drought which had occurred in the year preceding, most of the vegetation was apparently parched up except in those places where early showers had fallen, and it may be presumed that the migrants from the west were forced to concentrate on such green patches for food and breeding. This possibly led to the formation of the initial outbreak centres in the desert in June-July. It is also stated

that sample populations collected in south Bikaner and at Barmer in the first fortnight of July showed a preponderance of *transiens* and *gregaria*, similar to the facies of the incursion migrants found in July 1936 in Rajputana. With the passage of depressions from the Bay of Bengal over Rajputana, heavy rainfall occurred in August in several places in the desert, and various loose groups of locusts present in the eastern parts of the desert were possibly carried towards the west or south-west by the rainstorms and forced to concentrate in the desert. It is also likely that the adults from the early batches of egg-laying in June and early July were also partly included in the concentrations mentioned above. During visits paid at the beginning of October large numbers of black and yellow *gregaria* hoppers of the 4th and 5th stage are said to have been found in the west Bikaner and east Jaisalmer areas and in the Chachro area. Bands of very young hoppers are also said to have been found as well as numbers of adults concentrated in patches of cultivation. The swarms reported in the second fortnight of October in north Sind, eastern parts of Baluchistan, the south-western districts of the Punjab and in Bahawalpore State, as well as in Delhi, Gurgaon, Hissar and Muttra areas were doubtless derived from the infestations mentioned above.

The Locust Outbreak of 1926 : In January 1926, widespread and heavy rainfall occurred both along the coast and in the interior of Baluchistan. Extensive breeding is presumed to have taken place in February-April, and in May-June, local records show that large bands of hoppers appeared in the Kulanch area, and that swarms of pink locusts were met with in June, and found disappearing from the area subsequently. Similar locust infestation would appear to have been noticed also in parts of Kech and Kolwa valleys. These were evidently of the nature of incipient swarms which had been produced from a concentrated breeding of migrants from the coastal reks.

Locust swarms reported to have been found in Kachhi by the end of June and in Sibi early in July were presumably derived from the interior of Baluchistan and possibly also Iran. On the analogy of the incursion of 1935, it is very likely that similar incursions of migrant individuals had reached south-west Punjab, Sind and Rajputana and had begun to breed with the fall of good rain in July. Swarms reached the Lasbela area in August, and breeding commenced in that area with the heavy rain received at the end of August and in September. In the Rajputana desert areas, breeding continued in August and September, and with the passage of depressions across the desert, locusts apparently became more and more concentrated in the south-western parts of the desert, where heavy breeding was noticed in the Thar and Mallani areas in September-October. Pink swarms produced here began to invade Kathiawar, Sind, Baluchistan and the Punjab between October and December. In

1926, the earliest swarms were found in south Sind, whereas in 1940, the earliest swarms flew north-west and reached the southern districts of the Punjab. This was presumably because the bulk of the breeding was in the northern parts of the desert in 1940.

The Outbreak of 1923: Records of the Naib-Wazir, Turbat, show that large hopper bands were detected in April-May in the villages of Zarenbug and Hassadi in the Dasht River valley and that control measures were taken by the local authorities. By the end of May, the infestation reached Gabd and practically extended all over the valley, and by June the adult locusts disappeared from the area. In July locusts were reported from the Kachhi area, and presumably others migrated into the desert areas about the same time, but apparently swarming did not occur in summer.

The Origin of the Cycle 1912–1919: In 1911, incipient swarms are known to have been observed in the Dasht valley in early summer, presumably as a result of good winter rains and especially of good falls in March recorded all over Baluchistan. Breeding is also recorded in the Kachhi area in April-May. As the monsoon proved a failure all over the desert areas in June, July and August, there was little scope for breeding in summer. The winter rains of 1911-12 were light to moderate in Baluchistan, but the monsoon rains in the desert began early in June, 1912 and were fairly heavy and well distributed. In July and August, there were good falls in most places, and in south Marwar, there were some showers even in September. Prolonged breeding including the production of a second generation would appear, therefore, to have taken place, especially in the southern parts of the desert. The first swarms were noticed in the Thar area in September and numerous flights invaded the south of Sind and Mekran in October, November and December. The swarm formation of 1912 very much resembled that of the present outbreak, inasmuch as it immediately followed a year of summer drought in the desert.

Cycle 1900–1907: The year 1899 was a period of severe drought in the Rajputana desert area, and very few swarms were seen that year. Good rainfall occurred in the winter-rain areas in 1900, and was followed by good monsoon rains in the desert, as a result of which swarming started again in the desert and pink flights commenced in September-October, 1900, in Rajputana and Sind and reached Baluchistan and the Punjab in November-December.

Cycle 1889–1898: This cycle was preceded by a long break—1882–1888. In 1888, good winter rainfall would appear to have occurred, but the only evidence about the appearance of locusts is the record in the Sind Season and Crop Report of 3 swarms in July in the Hyderabad area. Presumably, some summer breeding had occurred in the desert of which there is no record. The

winter rainfall of 1889 was also good, and swarms began to appear in the Punjab, Sind and Rajputana areas as early as May. The monsoon was also early and rains began at the end of May, and continued till the end of August as a result of which extensive breeding took place.

Cycle 1869–1873: The year 1868 was a year of drought in Rajputana. The winter of 1868-69 was a wet one, and swarms would appear to have reached S.W. Punjab early in spring, and Rajputana in June. Heavy breeding occurred in the desert in July-August, and swarms appeared in the Thar area by the 15th September.

The data mentioned above would indicate the importance of the following sequence of events in originating a new locust cycle: (1) heavy and well-distributed rainfall in the winter rain areas in causing the formation of outbreak centres in the interior valleys of both Iranian and British Mekran, and bringing into existence the nucleus of future outbreaks, (2) the conveyance of these incipient swarms into the desert area at the right time for bringing about monsoon breeding, and (3) the occurrence of heavy and well-distributed monsoon rainfall to bring about concentrated and continuous breeding in the desert for building up large swarms. There would appear to be some reason to consider that summer droughts in the Sind-Rajputana desert have probably the effect of creating patchiness of vegetation at the beginning of the succeeding year's rainfall, which is perhaps instrumental in causing the initial concentrations of locusts resulting in incipient swarming.

The Importance of checking the Initial Outbreaks

At the last International Locust Conference held at Brussels in 1938, stress was laid on the importance of keeping under surveillance the areas known to be responsible for starting fresh outbreaks of locusts and of controlling the incipient outbreaks before they got out of control. The experience of past locust outbreaks has shown that it is difficult to bring locust infestations under control, once the swarms have begun to fly about and migrate to distant places. The best way of dealing with them would be to locate the centres of outbreaks and destroy the incipient bands of hoppers before they are in a position to acquire wings and leave the area. In the Indo-Iranian area of infestation, the primary outbreak centres are formed in the winter-rain areas—within the limits of British or Iranian Mekran, and perhaps also of eastern Arabia, where the transformation of phase from *solitaria* into *transiens* or *gregaria* may occur and sometimes even the formation of small, loose, flying swarms. Generally, however, the new generation would appear to migrate as groups of individuals rather than as swarms, as had happened

in 1935, to the summer-rain areas. If conditions are favourable here, small concentrations might be formed in June-July-August, and in case of the occurrence of good precipitation in August or September, the dynamics of the depressions from the Bay may bring about further concentrated breeding in the desert and the building up of large swarms.

In regard to the control of the outbreak centres, the present locust warning organization has been suffering from certain serious handicaps. In the first place, it is only the centres that are within British limits that can be tackled by the staff. As yet no information is available as to whether the co-operation of the Iranian Government has been secured in regard to a joint watch and control of the outbreak areas in the winter rain zone; for, without the simultaneous control of the Iranian centres, much useful purpose will not be served by the measures taken in Mekran only. Secondly, even in the Indian area, most of the outbreak centres are located either in distant hill-valleys in the interior of Baluchistan, or in wide expanses of the Indian Desert, and as most of them are situated in very sparsely populated country lacking means of easy communication, it has been found difficult, on account of the inadequacy of the staff engaged on this work at present, to detect cases of incipient swarming sufficiently early for purposes of control.

The Resolution of the Fifth International Locust Conference on this subject recommended the formation of an organization composed of staff financed by the co-operating governments, whose functions were to be chiefly (1) the permanent supervision of all outbreak areas—whether known or suspected, and (2) the immediate destruction of incipient swarms whenever observed.

The locust warning organization of the Government of India, as at present constituted, was not designed to undertake the control of the incipient outbreaks. Indeed, the present strength of the staff cannot be deemed to be sufficient even to patrol effectively the vast areas of locust habitat for the detection of the danger points in time. Since swarms have now appeared, the indications are that a new cycle of infestation has started, which will mean that further trouble is in store for the cultivator when these swarms begin to breed with the fall of winter rains.

Sunspot Cycles and Locust Periodicity

It is generally recognized that many of the natural phenomena noticed on the face of the earth are ultimately traceable to the energy derived from the emanations radiating from the sun, and it is not surprising that an explanation of the countless fluctuations found in various earthly phenomena, such as the daily weather changes and variations in the growth of

plants and animals, has been sought in the variations in the quality and quantity of solar radiation. Emanations from the sun are, on the other hand, found to vary with the number of the 'sunspots' noticeable on the sun's disc. Sunspots have been described as 'terrific cyclonic storms in the solar atmosphere generating powerful electro-magnetic fields', and the number of sunspots gradually increases for some years and then decreases, a single cycle of such changes being usually of eleven years' duration. Observations have shown that the occurrence of magnetic storms, auroral displays, and the fading out of radio transmissions in some years are all connected with an increase in sunspot activity. Harlan T. Stetson (1937) has shown in his fascinating book on 'Sunspots and their effects from the Human Point of View' that the growth of plant life varies directly with the increase in the number of sunspots, while in the case of animals there is an inverse variation. Swinton (1880) has adduced evidence to show that periods of prevalence of locusts generally coincide with those of sunspot minima, while Criddle (1932) found that outbreaks of grasshoppers in Manitoba (Canada), coincide with periods of sunspot minima, and Richmond (1938) also found a similar coincidence in British Columbia. Uichanco (1936) found a fairly marked negative correlation between solar activity and locust fluctuation in regard to the swarms of the Migratory Locust (*Locusta m. manilensis*) in the Philippines.

As, in the case of the cycles of infestations in north-west India, fairly detailed data were available since 1860, a graph was worked out showing the fluctuation in the infestation, based on the comparative extent of damage, the area of spread and the degree of oviposition, and superimposed on a graph of sunspot numbers for the corresponding period (Rao, 1938). The result was that a general negative correlation was found to be existent between the sunspot curve and the curve of infestation, except at two places, viz. 1905–07 and 1928–31. It was also evident that in almost all cases where a new cycle began after a break, the incipient swarms were mostly produced during the period when sunspots were either at their minimum or low in numbers.

It is rather difficult to imagine how sunspots could have any direct action on locusts unless the emanations from the sun can be deemed to have a prejudicial effect on their reproductive powers. On the contrary, the locust is entirely dependent on the occurrence of optimum weather conditions, especially favourable rainfall in the winter and summer rain-belts, for its multiplication, and since the world climate is ultimately dependent on the quantity and quality of solar radiation, it is quite conceivable that locust incidence may be indirectly affected by the fluctuation of sunspot activity.

The Need of further Research on Locusts in India

At the present moment when a fresh swarming of the desert locust has begun after an interval of over eight years, it would be useful to make a retrospect of the results achieved since the last great outbreak. At the time of the commencement of the last cycle in the autumn of 1926, when large swarms similarly appeared after an interval of over six years, our knowledge as to their origin and as to the factors affecting their movements and breeding was but limited.

In consequence of the widespread damage caused by locust swarms in India, western Asia and Africa during the last cycle, various research schemes were inaugurated in different countries and were in progress during the last decade; and as a result thereof a decidedly large advance has been achieved as regards our knowledge of their bionomics, ecology, breeding grounds, general movements and phase transformation.

In India, investigations were in progress since December 1930 under the scheme financed by the Imperial Council of Agricultural Research. As a result of intensive studies of the bionomics of the locust under controlled conditions at Lyallpur under the direction of Khan Bahadur M. Afzal Husain, very valuable information has been obtained in regard to the effect of various factors such as temperature, humidity, muscular effort, the proportion of carbon-dioxide in the atmosphere, etc., on the coloration and phase development of hoppers.

In regard to the search for 'the permanent breeding grounds' of the locust, invaluable information has been secured, showing that during swarm-free intervals (1) it lives as a solitary locust in the desert areas of Sind, Baluchistan and Rajputana, (2) regularly breeds in spring in the western winter-rain areas, and in summer in the monsoon areas in the east, being possessed of the ability to migrate from one rain-belt to the other at the change of the seasons, and (3) assumes the *gregaria* phase as the result of crowded breeding in ecologically favourable situations in the winter and summer brood areas, and of a rapid succession of generations following favourable rainfall.

The practical aspect of this knowledge lies in the fact that the locust is a perfectly harmless insect so long as it does not breed under crowded conditions and assume the swarming stage, and that it is fully possible to prevent it from breaking out into swarms if the *outbreak centres* are kept under watch and any incipient outbreaks that may be noticed are immediately controlled by the requisite staff. It is evident that once locusts are allowed to form into swarms they will migrate long distances and spread over a wide area, and it would then be difficult to control them except by adopting extensive measures at great cost and expense in the various provinces affected. It would, therefore, really be a kind of crop insurance to maintain a

competent staff provided with the requisite funds and material to watch the locusts in the desert areas and control the initial outbreaks as soon as they are detected.

It is, however, a tragedy of life that the human mind is generally unable to assess danger at its full value unless it comes actually face to face with it. While a locust infestation is in progress and swarms are actually making their presence felt, the public as well as the government are ready to spend vast sums of money to control the pest and are anxious to provide for scientific investigations to find out all about the activities of the insect. When, however, the outbreak subsides and the locusts disappear, all interest in the investigations in progress is lost in course of time and work is stopped before any legitimate conclusions can be reached. The observations made in the African and the Indian areas had clearly indicated the necessity of immediately dealing with incipient swarms for controlling a new outbreak in its early stages, but unfortunately the staff and the funds allocated for the Locust Warning Organization were obviously inadequate to enable it to control incipient swarming at the critical time. Numerous swarms have already appeared in rich agricultural areas, but by taking the necessary control measures, it should be possible to prevent it from developing into another cycle of locust menace.

Although a considerable advance has been made in a study of locust epidemiology, there are still various gaps in our knowledge of locusts, especially in regard to problems of a fundamental nature, and it is hoped that it would be possible to get the necessary funds for their investigation while material for study is available during the present swarm period.

Besides the Desert Locust, in the case of which, thanks to the funds generously provided by the Imperial Council of Agricultural Research, a great deal of essential knowledge has been acquired, there are two other locusts which are potential enemies of the agriculturist in India, about which little is known as to the exact conditions in which swarm formation takes place.

First, we have the Bombay Locust—*Patanga succincta* L., which is one of the serious locust pests of India. In the past, India has experienced several infestations, of which, however, we have detailed records of damage only in the case of the last two visitations, 1878–1884, and 1901–1908. The last outbreak of this locust was in full swing when the first Entomologist to the Government of India—the late Prof. Maxwell Lefroy—arrived in India and took up his duties in 1904 and the investigations carried out by him cover a great extent of ground. But, in the light of the locust lore of modern times, the problem of the Bombay Locust will have to be examined afresh, especially in regard to the location of its permanent breeding grounds, an investigation of the bionomics and ecology of the solitary phase

and the determination of the factors that have contributed to its comparative quiescence for the past thirty years nearly. This is all the more important, because the staff engaged in the surveys of the desert locust in the Rajputana desert areas have been finding every year solitary specimens of the Bombay Locust during the autumn and winter months in many places, though so far its hoppers have not been found anywhere in the desert, and there is little doubt that they form instances of long distance migration. Past records show that its visitations had descended rather suddenly on the public without a warning, and it would not redound to the credit of India if, sooner or later, Peninsular India all at once finds itself at the mercy of the marauding swarms of this locust. At present no attempt has been made to study the problem while the insect is in its solitary phase, and there is no organization to keep a watch over its developments and to check the outbreak in its initial stage.

Secondly, there is the Migratory Locust. Although it has generally been found in its solitary phase all over India, past experience has shown that it can, under favourable conditions, increase in numbers to such an extent as to assume serious pest conditions. In 1878, this insect invaded district after district in the southern parts of Madras, usually so free from the importunate attentions of locust swarms, but fortunately it relapsed into its usual status of a harmless grasshopper by the end of the year. In 1937, this insect was reported to be doing extensive damage to crops in October in Sirohi State and in the States of Kathiawar and Gujarat, and if its earlier activities in that year had not been traced by the Locust Survey staff, one would have thought that the infestation was only of local origin, whereas actually it originated in the hill-valleys of Baluchistan and spread into Kathiawar and Gujarat only after passing through heavy breeding in the Bikaner-Jaipur areas in July-August. At present, it is not known whether the Indian form is allied to the Tropical Migratory Locust of Africa or to the Eastern Migratory Locust of China and the Philippines, and it is only when the *gregaria* form is bred out that its systematic position can be determined. It would be of much scientific and practical interest to study it under controlled conditions and find out the causes that provoke its sudden outbreaks.

There are, besides the locusts, certain very injurious grasshoppers in India, which occasionally rear their destructive heads in certain years and occasion a great deal of damage. Of these, the Deccan Grasshopper, *Colemania sphenarioides* Bol., is one of the most important, seriously affecting dry crops over a very large area of Bombay, Mysore, Hyderabad and Madras. This also shows considerable fluctuations in numbers and possibly appears in cycles. Species of *Hieroglyphus* seriously affect both dry and wet cereal crops all over India and *Aeolopus*

affinis is also known to be a serious pest of dry crops in certain years in parts of India.

It is to be hoped that in course of time many of these injurious locusts and grasshoppers, which at some time or other cause considerable losses to the Indian cultivator, would be tackled either by provincial initiative and effort or by schemes of an all-India character, so as to bring relief to the man behind the plough, who, after all, is the man that directly or indirectly supports the whole machinery of Government, though, of course, it is somewhat of a forlorn hope at the present time, in view of the exigencies of war, to expect any considerable support for scientific investigations.

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SECTION OF ANTHROPOLOGY

President :—TARAK CHANDRA DAS, M.A.

Presidential Address

(*Delivered on Jan. 4, 1941*)

CULTURAL ANTHROPOLOGY IN THE SERVICE OF THE INDIVIDUAL AND THE NATION

INTRODUCTION

It is my first duty to offer you my sincerest thanks for the honour you have conferred upon me by electing me to preside over the deliberations of this Section of the Indian Science Congress. The subject of my discourse to-day is 'Cultural Anthropology in the Service of the Individual and the Nation'. We, Indians, are now passing through a stage in our national life when a clear statement of how anthropology can help to build up the future of India is not only suitable to the occasion but is an imperative necessity.

Anthropology is commonly believed to be a border-line science which has no practical application. This misconception is due partly to lack of knowledge of the scope of and recent advances in anthropology on the part of the ordinary man and partly to the anthropologists themselves who have in the past laid too much emphasis on the historical side of the subject. But recent trends in both physical and cultural anthropology show a definite change in the angle of vision and the study of the present is seriously replacing that of the past. Professor Le Gros Clark has given us a very clear idea about the applied side of Physical Anthropology in his Presidential Address before the Anthropology Section of the British Association for the Advancement of Science at its Dundee Session in 1939. I do not propose, however, to tread over the same ground again, but intend to confine myself to Cultural Anthropology alone.

Before going to show the place of Cultural Anthropology in the life of the ordinary man of diverse professions we wish to draw attention to one general condition which affects all the different groups equally and which shows how Cultural Anthropology is ultimately connected with them. You are all well acquainted with the law of demand and supply in economics. An institution does not come into existence if it has no necessity for the community in which it flourishes. We hear that this

law is equally applicable in the biological world. Anthropology as a science is of no ancient origin. We may say in round figures that during the last 100 or 150 years at the utmost this subject has developed to its present volume and importance. The history of the world shows that during this period better means of communication arose and the European nations spread over the world and established political supremacy over or commercial connections with diverse races and cultures. This contact between the European races and the coloured peoples of the earth has brought to existence the Science of Man. The early traders, conquerors and missionaries tried to understand the people with whom they came in contact. Every one of them, whether an administrator, missionary, merchant, soldier or planter, required to be sympathetic in dealing with persons of his own or alien race. It has been claimed by one of the early stalwarts of Indian anthropology that 'sympathy is one of the chief factors in successful dealings of any kind with human beings, and sympathy can only come of knowledge. And not only also does sympathy come of knowledge, but it is knowledge that begets sympathy............. Familiarity breeds contempt, but it is knowledge that breeds respect and it is all the same whether the race be black, white, yellow or red, or whether it be cultured or ignorant, civilized or semi-civilized or downright savage'.[1] This knowledge which breeds sympathy was supplied by the men who came to settle among alien people for purposes of business. They recorded the manners, customs, beliefs and superstitions—in a word the life of the people among whom their lot was thrown. This volume of literature forms the bed-rock of Cultural Anthropology. These records are not always perfect for scientific purposes as they are not the products of trained scientists yet they give us the fruits of observation made by the practical men who tried to solve their own difficulties and recorded their experiences to help and guide others who might have to face similar difficulties in their own fields of activities. The deductions of modern Cultural Anthropology are based on these observations of practical men and the subject itself owes its origin to them. This clearly indicates the service which Cultural Anthropology rendered in the past to the different human professions and it may be reasonably expected that it will render the same help in future, perhaps in a better manner as it is more perfectly organized now. So, the Law of Demand and Supply shows that anthropological knowledge was necessary at the beginning of European expansion and the early settlers by recording their experiences among alien races laid the foundation of a science which has already secured a place among its sister subjects and dreams of a future fraught with immense possibilities.

[1] Sir R. Temple—*Indian Antiquary*, Vol. XXXIV, 1905, p. 133.

We hope, you have already a glimpse of the necessity of cultural anthropology in modern life and it owes its origin to this necessity. But we shall try to convince you further on this matter by a detailed study of the part which this subject plays in the life of the ordinary man.

Place of Anthropology in Trade, Industry, and Agriculture

Trade, industry, and agriculture are the three most important institutions of modern man. Our life and culture depend on them. They are the sources of livelihood of millions of our brethren. Let us see what part anthropology plays, in these three departments of modern culture. Trade is mostly based on industry and agriculture. It means distribution of goods produced by agriculture and industry and the law of demand and supply governs this distribution. 'Who is successful in commerce but he who finds out where the market is, and having found the market, knows how to take advantage of it and what to avoid? In seeking a market, the habits, ways, predilections and prejudices of many kinds of people have to be learnt, and this is the case in a much higher degree in preserving the market when found.' Many a foreign market has been lost by the merchant and the manufacturer through their ignorance of the local people and their pride born of the same ignorance. It is often argued by the manufacturer that he is not going to change the mode of production of a particular article in response to a demand from a foreign market but would stick to the method he found suitable for the consumers in the home market. Nothing is more foolish and ruinous and this had been the case with a number of British firms in the early days according to an experienced British administrator. No one will take a thing which he does not like or cannot pay for whether he be civilized or savage. Among the primitive the prejudice is more strongly felt. 'Beads as beads do not appeal to the savage but it is a particular kind and form of bead that he wants for reasons of his own, practical enough in their way—and so on through every article of trade.' Sylvia Leith-Ross in her *African Women* points out, in this connection, how European commercial concerns consult the opinion of Ibo women traders about the suitability of patterns received from England and introduced in the area. Their views receive serious consideration from these mercantile firms. If you go to the interior of Chota Nagpur, you will find nowadays hundreds of rupees worth of glass beads and bangles being sold to its primitive inhabitants by the local traders. Most of them come from Japan and pass through Calcutta. But only half-a-century ago or even less these glass articles were unknown to them. Lac beads and bangles manufactured in and near about the region by the local people

were in use at that time. Chota Nagpur is reputed for its lac in the world market even to-day but in spite of this the local product could not successfully fight against the foreign article. The secret of Japan's success in this department lay in her minute study of the local taste, demand, and paying capacity. The local producers did not pay any heed to these three factors which constantly change, however minutely, with progress of time and the result is that they have been wholly ousted from the market. Brass and bell-metal industry of Bengal is also faced with the same fate at present. Aluminium utensils are vigorously pushing their way into the rural parts of Bengal and the workers in brass and bell-metal will soon pay the penalty for their neglect.

Dress and ornaments show how taste changes with the passage of time. Social, political and economic factors contribute in a more or less degree towards the formation of fashions of a people. This may be illustrated from a study of the history of even such an insignificant trait as the ladies' foot-wear for the last twenty-five years in Bengal. Post-war impetus to female education, non-co-operation movement in politics and general trade-depression all over the country have operated in the origin and growth of this trait. Numerous instances of this nature may be brought forward and they show what an intimate knowledge of the social, political, religious, and economic life of a people is necessary if you wish to be a successful supplier of goods to them. A false step or a little laxity in the constant watchfulness may ruin the business. This intimate knowledge about a large section of humanity is supplied by Cultural Anthropology and the trader and the industrialist may profitably employ this knowledge to the furtherance of their aims. They may employ young men trained in anthropology to conduct their business in far off countries with instructions to keep their employers informed about even the slightest changes in the life and manners of the people among whom they may be stationed. Many important firms in England have appreciated the force of this argument and now employ such anthropologically trained young men to conduct their business in foreign markets. Indian students of anthropology may also be employed in the same manner by Indian firms though unfortunately their scope is very limited and our mercantile community not so advanced in their ideas. This is, however, a circumstance for which our subject is not responsible. It may be urged that the kind of knowledge noted above can be and had been successfully acquired by men who have or had no anthropological training. 'Granted, but the man who has been obliged to acquire it without any previous training in observation is heavily handicapped indeed in comparison with him who has acquired the habit of right observation, and what is of much more importance, has been put in the way of rightly interpreting his observation in his

youth.' This is how the anthropologist helps the trader and the industrialist and is in turn helped by them.

Besides supplying information to the industrialist regarding the nature of things required by a particular market the anthropologist can help him in other spheres as well. The old days of home-industries are gone. The invention of modern machineries has centralized productions in big factories. This has brought about the struggle between capital and labour which is occupying the attention of all serious-minded people in every country of the West. In India, though the fight between labour and capital has not reached the same degree of acuteness, it is gradually gaining ground. In our country labour is often supplied by the primitive tribes. In the mines and factories of Chota Nagpur thousands of labourers are employed and they are mostly recruited from amongst the tribes which occupy this part of the country. The tea-plantations of Assam are also worked by labourers mostly recruited from the tribes of Chota Nagpur, Orissa and Madras. The treatment which these labourers receive from their employers shows utter ignorance of their life and customs. This leads to lack of sympathy on both sides and consequent misunderstanding. Troubles naturally crop up under these circumstances entailing huge loss of money to the employer and the employed. But this can be easily avoided with a little knowledge of anthropology. Petty grievances which can be removed by a sympathetic master at a nominal or no cost often assume huge dimensions when they are not attended to at the outset.

Big scale farming also involves the question of labour and capital. The planters of Assam and Ceylon employ tribal labour to a very great extent. They try their best to exploit the labourers to the utmost degree and do not make any attempt to understand their difficulties. This unsympathetic attitude is at the root of much human misery which can be easily avoided by a little knowledge. I need not point out that there i much difference between voluntary and forced labour; the worker must feel pride and pleasure in his work; he is to be tuned to offer his services and not made to feel that work is being extracted from him. This psychological attitude is more paying in the long run and this can be achieved only by an intimate knowledge of the life and traditions of the workers, by a knowledge of their past happiness and present difficulties. Anthropology supplies this knowledge more than any other branch of learning. These tribal labourers uprooted from their native soil and planted temporarily in and around work-centres lose practically all contact with their own people. They no longer find themselves under the benign control of their family, clan and village elders, each and every one of which units exercises a very judicious check over the individual inclinations in their homeland. Free from these controlling agencies to whom they always look for

guidance whenever occasions arise these simple men from the hills and jungles fall easy prey to the vices common in such areas. Moreover, they are often misled by wily interested people to commit actions the full import of which they can hardly realize. In such circumstances arise most of the labour troubles in work-centres and it is the duty of the employers to realize the situation and arrange for their redress. Strong measures only toughen the stuff but a little sympathy with more knowledge may easily soften the situation. This is where anthropology brings in practical relief to the producers.

Anthropology in Law and Legislation

Let us now see how anthropological knowledge can help the members of some of our noble professions as for example the lawyer, the educationist, and the missionary. A lawyer practising in a primitive area should know in detail the manners and customs of the people who may come to him for legal advice and help. Unless he is well acquainted with the life of the people he cannot properly represent his client's claims before the judge. The judge also requires an intimate knowledge of the people among whom he has been placed to dispense justice. This is more so in a primitive area. The primitive peoples have different notions of law and their ideas of grievances sometimes differ from those of ours. The law of limitation, as for example, does not exist among some of the Kuki tribes of Assam. When a man borrows money he is to pay it back whenever convenient and there is no hurry on either side. It may be realized from him or from his son or grandson or any other descendant lower down. It is never barred by limitation. Just imagine what a money-lender in such an area thinks of when he hears that the borrower is not required to pay back the loan as it has not been sued for in time according to our custom or law. In Chota Nagpur, again, marriage by force is an established custom among some of the tribes. Nobody thinks it to be a serious crime and cases of this nature are not infrequent in this area. If these cases are brought to the court and punished according to our estimation of the magnitude of the crime it will be sheer injustice. Some magico-religious conceptions also deserve mention in this connection. Belief in witchcraft is a common feature in many primitive areas and sometimes leads to very atrocious crimes by parties of villagers working together. From time to time we hear of murder of old women, suspected to be witches, from tribal areas. The intensity of the crime cannot be realized until and unless we understand the mental and cultural outlook of the people concerned in such crimes. Instances of human sacrifice to different deities in fulfilment of vows or for boons come to our knowledge occasionally from similar areas. The administration of law in these and similar other cases involve a

consideration of the magico-religious beliefs and superstitions of the culprit and his community. At least a part of the responsibility of such crimes lies with the cultural make-up of the people to which the perpetrator belongs. Promulgation of the laws of civilized life among a people of this type without previous education to uplift their cultural condition is unjust and injudicious. As long as the beliefs and superstitions of such a people are not eradicated by education and new values established in their place the laws of civilized life cannot be introduced among them with justice. This shows how the administration of law requires anthropological knowledge even where its sections are clear and the evidences complete to punish the accused. There are innumerable instances of this nature and the lawyer and the judge must be thoroughly acquainted with the people in order to evaluate properly the facts laid before them and their interpretation too. Without this intimate knowledge, both of them may fail to discharge their duties in a suitable manner.

Legislation is a more important field than administration of law for the employment of anthropological knowledge. We all know that most of our laws are codified customs and customs form an important branch of anthropological studies. Primitive society is guided and controlled by immemorial customs and many of them differ in their essential values from our conceptions. We have already pointed out how magico-religious and socio-economic conceptions of these backward peoples differ from those of ours and even a cursory study of any of our primitive tribes will convince you how they have built up their culture round these ideas and conceptions. Under these circumstances introduction of our laws amongst them often tends to maladaptations and consequent decay or degeneration of tribal cultures. Speaking about Africa, Lord Hailey, G.C.S.I., G.C.I.E., one of its greatest administrators, expressed his doubt about the possibility to evolve a homogeneous system of law by reconciling the native customary law with the European law. In the chapters on law and justice and land of his monumental work *African Survey* he points out how conflicting the ideas and interests are in the development of land-tenure and warns the government about all attempts at premature interference especially in this field.

In our own country examples are not rare of hasty legislation which have either proved dead laws (when they are mere permissive) or have definitely been harmful to the whole or part of a community. An instance of the former type is the Widow Remarriage Act which being a permissive law has proved innocuous and has not been able to strike at the root of the evil and solve the problem for which it was intended. If we are to believe, what Mr. J. M. Dutt has shown in the pages of the *Modern Review* (Jan. 1940, pp. 36–41), that enforced widowhood is ultimately responsible for the gradual decrease of Hindu

population in Bengal, then this law should be turned into a coercive one in the interest of national welfare. Here we require the help of the social anthropologist who will point out by intensive investigation the advisability or otherwise of promulgating a coercive law of this nature. Another instance of a futile Act of this type is the Sarda Act of 1929 which prohibits marriage of children. The aim of this Act is evidently to stop marriage before physiological maturity which is the only justification for such a measure against a very important socio-religious and economic institution. But the age of marriage legally allowed by this Act falls far short of physiological maturity. British India even falls short of what has been prescribed by some of the Indian States and readily accepted by its people. Such a measure should have been preceded by a wide and intensive study of its socio-economic implications and the prevailing opinion of the people. Who is better fitted for this task than the cultural anthropologist? There are talks to restrict Hindu polygyny and to introduce divorce amongst them by legislative measures but we are afraid that these also will meet with the same fate which overcame their predecessors in the domain of socio-religious legislation. At every stage in the passage of such Acts orthodoxy clamours unceasingly against these so-called re-actionary measures and almost in every case successfully amputates the well-conceived measures and the promoters of the latter are not armed with the requisite facts and figures to fight against the age-old conservatism of our country. The result is a half-way compromise which practically nullifies the original motive of the measures. Such half-hearted actions not only retard future progress but also lull into quiescence the spirits of change and progress.

Society is, as it were, a huge organism. If you strike it at any one point, all its parts feel and react. One should be cautious before he attempts to strike such an organism. The Permanent Settlement of Lord Cornwallis brought about a Hindu landed aristocracy in Bengal in the early years of British rule out of political and financial exigencies. The system of inheritance practised in this part of the country has for the last 150 years gone on dividing these holdings generation after generation reducing their size and income. Thus a large class of petty landholders came into existence. European trade with the development of Calcutta as the most important centre for export and import business with Europe attracted a large number of these small landholders and gave employment to them. Besides this, the conquest of the whole of India with the wealth of Bengal and with Calcutta as the base, provided further employment in government service to a large number of the sons of the same landed community. Moreover, this community realized at an early stage the importance of English education and unhesitat-

ingly gave up the indigenous system in favour of the novel importation and thereby prepared themselves for the part which they have played in the development of British trade and British political supremacy. What they suffered in this new adjustment need not be reiterated here. Suffice it to say that this is mainly responsible for the dismemberment of the Bengali joint-family and the subversion of the land-economy of the country especially in its middle class population whereby thousands lived on the direct products of the land. The strong Hindu middle class which has been brought into existence by requirements of British rule and British trade forms now the pride of the country—a community which has its roots deep into almost every nook and corner of our socio-economic life. The recent recommendations of the majority of the Floud Commission to abolish this permanent settlement naturally raises grave doubts and graver suspicions in the minds of anthropologists about the judiciousness of hurrying into such a step. Such an Act, according to the estimate of the commissioners themselves, will involve directly about two and a quarter millions of Bengal's population. Indirectly it would affect a much bigger number and its stupendous effects on the social and economic life of the province cannot be realized at this stage. Experiences of African experiments should guide our legislators in this difficult situation and I would not hesitate to draw their attention to what has been said by Lord Hailey in comparable circumstances and referred to before in this discourse. A thorough and sifting enquiry by a band of competent social anthropologists in urban and rural centres and among all classes of peoples who are directly or indirectly connected with the problem is necessary to assess the effects of such a revolutionary measure. It is not the task for a Commission composed of persons who have no personal knowledge of or contact with the life of the millions who have been placed at their mercy. Nor is it the task of the economist or sociologist alone but we require one who combines both these sides and something more and that is a sympathetic knowledge.

Owing to improvement of facilities for travel and transport and lack of food and employment in the densely populated areas of advanced countries civilized people have moved and are still moving towards the more backward parts of their own or other countries. This has brought them in contact with the primitive peoples inhabiting the more inhospitable regions of the earth. Besides this, the more intense exploitation of the natural resources of the country by capitalists and business corporations has necessitated the importation of cheap labour to mining centres, industrial works and cash-crop gardens of the different undeveloped areas. And cheap labour is supplied by the tribal peoples. This has brought into existence vast areas of culture-contact wherein the savage and the civilized are nowadays living side by side trying to adjust themselves as far as possible

to each other's cultures. But in this attempt at adjustment the savage has always a losing game to play. He is no match for his wily neighbour who always tries to exploit him in every way possible. The result is the growth of a number of maladjustments in social, religious and economic life of the less advanced and this is undermining the strength and vitality of these people. Here we shall consider only the legal implications of such culture-contact.

India possesses a vast area of culture-contact wherein primitive tribes from neighbouring hills and jungles have come down to live among its civilized peoples. All along the foot hills of the Himalayas we have a vast area of this nature. The border districts of Bengal towards the east form an area of such culture-contact between the Mongoloid peoples of Assam and the Bengalis. A similar area is also met with on the western front of Bengal and this is practically the story of many other provinces of India. Besides these border areas, there are culture-contact regions even in the heart of a number of provinces such as the tea gardens of Assam, the coffee plantations of Madras, the mining districts of Bengal and Bihar, etc. The total population of these culture-contact areas of India runs into several millions, and this sufficiently indicates the magnitude of the problem.

These areas are generally governed by laws which are suitable to the more advanced communities. But this has given rise to a number of maladjustments. We shall consider here only one such case—that of the Garos. A large number of people of this tribe have come to settle in the plains of Mymensingh at its northern boundary just below the Garo Hills. The dominant people here are the Bengalis among whom they have established their villages. The Garos of the Garo Hills are a matrilineal, matrilocal people among whom property is owned by the women-folk and men have no right over it unless it is self-acquired. There is a special system of inheritance by which one of the daughters is selected (*nokna*) to inherit the property of the mother. This system worked quite satisfactorily so long as the Garo stuck to their hill home where temporary hill cultivation is practised. Land, in this area, has no intrinsic value of its own as the same plot does not produce any crop for more than 3 or 4 years at a stretch after which it has to be left fallow for 10 to 20 years to accumulate mould in order to be ready for another cycle of cultivation. The house, another important item of property in the plains where it costs a lot of money, is not of much importance in the hills where the materials are available in the neighbouring jungles without payment and the labour is provided in each case, free of charge, by the villagers themselves. Besides these, that is, land and house, the hill Garo family of ordinary means possesses a few domestic utensils and agricultural implements, most of which are manufactured by the householder himself. Thus the question of inheritance does not loom large in such a community

and the sons of the family easily go over to their wives' place leaving to their selected sister and her husband all the property of the family. Moreover, in such communities, accumulation of wealth in particular hands is a rarity as the system of economy is not suitable to its growth. Under these circumstances the migration of Garo families to the plains of Mymensingh with a different system of land-economy, that is, with permanently cultivated fields and with the possibility of accumulation of money in individual families, has led to a change in the outlook of Garo sons and their fathers. They no longer like the idea of leaving the permanently cultivable land to the *nokna* and her husband and a conflict has come into existence. The recent revenue settlement of the district has brought out the nature and extent of this conflict, and the Department of Anthropology of the University of Calcutta was invited to investigate into this problem. Very interesting facts have been revealed by this study of the Garo law of inheritance in the plains which fully justifies the claims of anthropology in the elucidation of problems of culture-contact.

Africa shows innumerable problems of culture-contact in connection with law and justice in its different areas. At the invitation of the Bechuanaland Protectorate Administration Prof. Schapera studied the laws and customs of the Tswanas and showed that a proper understanding of them depends on an examination of the nature and functions of the political, territorial, kinship, age and class groups. This relationship between different persons and groups form the background of primitive law. Law in primitive society does not depend on State sanction alone but has its roots deep in the life and traditions of the people and stands on sanctions of a very different nature some of which are automatic, others magico-religious and the rest derive their sanctity from public opinion. This is the secret of primitive administration. Without an executive authority or sometimes even a judicial body, law and order are maintained in primitive society as if automatically. This is why we advocate the employment of social anthropologists both in the administration of the old laws and the promulgation of new ones. This is no less applicable in case of advanced communities. Legal measures affecting the economic system of the country are referred, as a rule, to the specialist in that particular branch of economics which is affected by the measures. But this is not the custom in India, at least, when social legislation is attempted. The specialist is not consulted but the opinion of the lay public and the whims of our legislators decide the fate of such measures. Moreover, the Government do not possess any information, beyond what is supplied by the Census Reports, on the socio-religious life of the people. I need not dilate on the character of the information supplied by these Census Reports and the nature of their origin as they are well known to all of you. I have

already stated that society is as it were a complex organism and when you strike such an organism at any one part, all other parts respond to it almost immediately. The large number of traits—social, economic and religious—which compose the society are all intimately interlinked and the social scientist has made it his business to study this system of linkage and is thus able to indicate how these links will behave when one of them is affected by a piece of legislation. The opinion of laymen, however erudite and considerate they may be, will at best take into consideration a few aspects of the question which have possibly come under their personal knowledge and not the whole system of linkage. The social scientist on the other hand draws upon the accumulated knowledge of his science and shapes his views according to this knowledge and his own experience and the requirements of the particular case. He also requires help and this in the shape of detailed information about particular problems and general sociological knowledge of the country in which his sphere of work is limited. This leads us to the question of an intensive sociological survey of the country. As social scientists we must arm ourselves with a detailed knowledge of our society scientifically collected by a band of trained men under expert guidance so that we may in turn arm our traders, industrialists, legislators, educationists, social reformers, and administrators, to fight in their respective fields. Society is not a static body; it is always changing and this corpus of knowledge accumulated at a particular period of our national life must be kept up to date by recording the changes constantly taking place in our life. This is how social anthropologists can help the country in the promulgation of new laws and this is where they should be consulted if we wish to avoid dead laws and half-hearted measures.

Anthropology in Education

Educating the primitive is a dangerous task: it is beset with numerous difficulties which are hardly realized by anybody except the anthropologist. In culture-contact areas it assumes even greater complexity. The Report of an Educational Conference of the Pacific region [1] points out how effectively it moulds 'native institutions, standards of living, moral codes and inherent values', and claims that it is more potent than even the direct attacks by the State and economic factors. The Conference frankly admits 'that when we institute a system of education we do not know precisely what we are doing'. It pointed out how the anthropologist can serve the educationist by placing at the latter's disposal the results of investigations

[1] *Education in Pacific Countries* by Felix M. Keesing, Professor of Anthropology, University of Hawaii, Oxford University Press, 1938.

into indigenous cultures especially his knowledge about the inter-relation of social, economic, legal, religious and political ties which are the main supports of the community. Investigators in Africa also sing at the same strain. Mr. H. S. Scott, in a discussion about East Africa, remarked that though anthropological knowledge has been utilized for administrative purposes to a certain extent, it has not been drawn upon for education of the primitive children in Africa. The result, according to him, is subversive of native interest. Major Hanns Vischer, Educational Adviser to the Colonial Office, drew attention to the necessity of inculcating a moral code as an element of native education. The introduction of Islamic or Christian moral codes in native educational system of Africa does not meet with his approval. Comparing the West African students in London with the graduates of Achimota, he remarks how the former suffer from lack of a code of values of their own which only can support a man when he is separated from his own environment. The graduates of Achimota, according to him, on the other hand, having been trained to regard native customs and traditions as worthy of respect, are not subjected to this limitation. Major Vischer urges the anthropologists to work out a morality based on present sociological realities which, he hopes, will fulfil a serious want in the native education of Africa and will substantially help to smooth the clash between modern morality, imported by natives brought up in European contact or trained in Christian schools, and tribal morality.

In the matter of tribal education India does not differ much from Africa. Rather, the problem is more complicated here. In our country, besides the activities of the Christian Missionaries we have to reckon with the institutions of the advanced Indians who also have been subjected to a system of education which can hardly be characterized as suitable to their manners of life, congenial to their traditions, or helpful in the solution of their national or individual economic problems. To-day I shall not deal with the educational problems of the advanced Indians though, I may assure you, the anthropologist has a definite part to play even in this sphere of our national activities but I shall confine my remarks to the tribal communities of India.

We have already remarked how the various tribal communities of India have come in contact with the advanced Indians and the Europeans. Attempts have been made to educate the primitive children both by the government of the country and by various philanthropic individuals and institutions the most important among the last being the Christian Missionaries. I reserve my remarks about Christian Missionary education for a later section.

Education is perhaps rightly claimed as the panacea of all evils that befall mankind. But people differ in its definition,

and naturally it has different types. There is one kind of education which uplifts the individual morally and intellectually and makes him fit for the struggle for existence. There is another kind of education which is intended for the exploitation of the so-called educated. There is a third type of education which the enthusiasts in their zeal for ameliorating the condition of the poor and the ill-fated impose upon them without considering their necessity or capacity. We have neither time nor inclination to discuss this point here but suffice it to say that much labour and more public money have been squandered and are still being squandered in imparting education which does neither suit the people nor help them to put a morsel of food into their mouth. On the other hand, it often creates a group of drones in the society who disdain labour of all kinds being proud of their so-called education and live as parasites. Where the imposition of a particular system of education is due to wilful commission, we have nothing to say but where it is not so, the anthropologist can, no doubt, help the educationist with his advice.

Speaking about the type of education worth imparting to American children the multi-millionaire motor-monarch Mr. Henry Ford, who turned an amateur school-teacher at the age of seventy-five after his retirement from business, remarks 'Education is not something to prepare you for life, but rather a part of life itself. Earning should go hand in hand with learning. These little children in school, earning money with their vegetable garden; teaching each other their own experiences; helping each other to plant and cultivate,—THEY are getting REAL education. For, true education consists in learning to do, by doing; learning to help, by helping; learning to earn, by earning.' This is from the pen of a man whom we may regard as a true representative of the materialistic West and who has risen from the masses and built up his fortune inch by inch by dint of his own labour. Now let us see what the spiritualistic East regards as the true type of education for modern India. '............. as to primary education my confirmed opinion is that the commencement of training by teaching the alphabet and reading and writing hampers their intellectual growth. I would not teach them the alphabet till they have had an elementary knowledge of history, geography, mental arithmetic and the art (say) of spinning. Through these three I should develop their intelligence.' 'As to the necessity and value of regarding the teaching of village handicrafts as the pivot and centre of education I have no manner of doubt. The method adopted in the institutions of India I do not call education, i.e. drawing out the best in man, but a debauchery of the mind.' This is the opinion of Mahatma Gandhi. Now we may ask, is there any fundamental difference in the views of these two great men of the East and the West? We, however, do not

find any. We are to remember that this system of education is advocated for the children of the advanced people and if you visit the tribal areas you will realize how much more imperative it is for them. An example from one of our tribal zones will clearly bring out how blindly we are following the trodden path.

The Valley of Manipur surrounded on all sides by lofty hill ranges is a secluded spot where its inhabitants have developed a culture of their own under ancient and medieval Hindu influence. The land is very fertile and the people are mainly agriculturists. The Manipuri women are reputed for the textiles they weave on their simple looms. Thus, the people do not suffer from want of food or clothing. The few other industries and trade are subservient to these two basic occupations. Here, a few High English Schools have been established for the boys and one for the girls too and there is an attempt to establish a college. A net-work of primary schools exist throughout the State. I found two such institutions in two Kuki villages and there are many more in other villages inhabited by the hill tribes. The two schools I saw used to teach their students how to read and write Meithei besides a little arithmetic, which they managed to forget within a few months after their departure from the school. This I say from personal experience. We cannot understand how this type of education can benefit the Kuki boys. It does not help them to earn a single farthing nor does it teach them the means of improving their agricultural methods on which their life depends. It is rightly argued that primary education opens the vistas of knowledge to the illiterate, but not to those who forget whatever they learn within a few months of their leaving the school. This requires a tradition and other extramural facilities which the tribal society lacks. In a press communique issued by the Madras Government on 26th June, 1937, just before the Congress ministry took over the charge of government we meet with the following remarks: 'In the whole of India 74 per cent of those who attend primary schools fail to reach class IV where they may be said to attain permanent literacy. In Madras the wastage is as much as 69 per cent, in the United Provinces and the Punjab 75 per cent; Bombay 59 per cent and C.P. 52 per cent are better, but Bihar and Orissa with 85 per cent and Bengal with 80 per cent wastage are the worst.' If this be the percentage of waste among people who include both advanced and tribal groups, you can easily imagine the condition among the latter group alone.

This system of educating the aboriginal is at best futile and results in useless expenditure of money. Further it is difficult to understand how high school education will help Manipuri agriculture or textile industry. The employments at the disposal of the State are very limited and the students who pass out of these schools every year will increase the number of the

unemployed as they no longer think of going back to their fields. During the first few years they will be idolized by the community but this will soon pass away when they will be looked upon as parasites and it is not impossible that they will be a source of trouble to the State. The education which was intended to produce a race of clerks for the East India Company has no justification for its introduction in a Native State like Manipur. Instead of copying what has been forced upon Bengal, Manipur could have evolved a type of education suitable for its subjects with a view to improve the two main occupations of the people, namely agriculture and textile industry.

In Manipur every girl has to learn weaving if she wants to get married. Every one tries to excel every other in this art. This was and this still is the ideal of Manipuri womanhood. But the establishment of a high school for the girls is sure to affect adversely this homely and useful ideal. In a few years more, I am afraid, the ideal wife will be one who knows how to read and write and not she who weaves well and an old useful industry will be sacrificed at the altar of so-called modern culture. Mrs. Sylvia Leith-Ross in her study of the Ibo Women of Nigeria refers to a similar effect brought about by English education spread by Christian Missionaries. Though a higher bride-price is claimed for girls with this type of education even to-day, yet already Ibo men have begun to prefer uneducated wives who are less expensive but more efficient. Men and women contribute equally to the solution of the bread-problem among the Ibos and the present system of education which merely trains the girls to play the part of fine young ladies lead them and their husbands to more and more uncomfortable situations. If you investigate the missionary attempts in the District of Ranchi in Chota Nagpur to educate the tribal people you will perhaps find the same condition.

Besides helping to find out the proper type of education to be imparted to a people anthropology may also assist in creating suitable teachers for such areas and this is equally important. Juvenile mind is attracted by sympathy and a successful teacher is one who can attract his students. We have already stated that sympathy is born of knowledge. When a teacher from a higher class or culture comes to a school where the students are recruited from a backward people he generally assumes a patronizing attitude and often looks down upon his pupils. Though this may not find any outward expression yet every student realizes it in a very short time almost instinctively and this makes them apathetic or even sometimes inimical towards the teacher. Love and respect of the students are the two most important assets of a teacher. His success depends on them. Moreover, if a teacher is not acquainted with the home-atmosphere of his students it is difficult for him to combat with the evils which originate there. Thus character and

knowledge are the two most important factors in the make-up of a good teacher and this is dependent to a great extent on Anthropology.

Anthropology and Social Service

In recent years a number of philanthropic or religious missions have sprung up in India among the children of the soil. But they cannot be compared with the Christian Missions of Europe and America either in magnitude, organization or influence. In spite of this, the Indian organizations are slowly gathering strength and they have a fair field and fruitful future. Though these Missions are now being worked by philanthropic people who have devoted their lives to the service of suffering humanity, yet this stage is sure to pass away and will be followed by a more organized one when specially trained people will be necessary to carry out the work. In Europe and America, missionary work has provided employment to a large number of students of anthropology and India also will provide the same in the near future.

Missionary work may be classified into different categories according to the main aim and ideal of the group. There are social missionaries, political missionaries and religious missionaries. But each one of them combines the functions of the other two to a certain degree and so each class is equally potent to bring about good or evil to the people among whom it works. They represent disruptive forces and the very nature of their work is responsible for this character. They introduce new ideas about social behaviour, political thoughts and religious beliefs and practices. The established order of the community is attacked at different points—points which are comparatively more vulnerable—and a breach at one region is the precursor to more at others, and at last the deluge comes. The less advanced the community the more exposed it is to the preachings of these missionaries. I do not, however, deny that many of these bodies have rendered ideal service to our less advanced brethren. They have brought medical relief to thousands of suffering humanity, they have introduced hundreds of thousands of our ignorant brethren into the mysterious temple of the goddess of learning and they have put food into the mouth of millions of starving population. It is all true but all these have not been given free; for every patient relieved, for every letter learned and for every morsel of food a price has to be paid. It is high time to examine both sides of the scale, to find out whether the price paid is commensurate with or exceeds the so-called gift. For this purpose we shall not subject to an examination the Indian missions which are more or less weak imitations of the Christian missionary organizations of Europe and America, but shall assess the value of Christian missionary

work and that not in India but in Africa because the Dark Continent perhaps shows the maximum activity of these Missionary organizations and there has been practically wholesale conversion in particular areas and tribes. There are, in Africa, tribes with authentic records about social, economic, political and religious systems of pre-Christian days and trained anthropologists have studied such groups in recent years with a special view to find out the effects of Christianization. Such a group is the Baganda of Uganda and Dr. L. P. Mair in assessing the effect of Christianization writes 'Christian missionaries have set their faces against all the patently "uncivilized" aspects of native culture, whether or not they were directly forbidden by the Scriptures: they have opposed polygamy, slavery, the payment of bride-price, initiation ceremonies, dancing, wailing at funerals, and the belief in magic, along with human sacrifice and the exposure of twins .... yet, to the anthropologist who sees culture as an organic whole, even those institutions which seem in terms of human suffering most cruel will be found to have some place in the maintenance of the society, such that their uncomprehending destruction must carry with it the loss of essential elements in the social structure; while the condemnation of others will prove often to be due to mere failure to recognize their positive value.'[1] According to the same author there are factors of great importance for the individual for which control is provided by magic. Christianity does not supply any substitute for it. Cure of disease, faithfulness of a wife, capacity to pay off debts and success in business are a few of these factors for which Christianity has failed to replace magic. In the same society Christianity has destroyed beliefs about automatic supernatural punishments especially those relating to unchastity. The result is laxity in sexual morality and Christianity has not been able to set up the moral standard of European society in this African community. In conclusion Dr. Mair writes 'Regarded strictly in its religious aspect, as a system of beliefs and practices to which man turns for reassurance in facing the unknown and confirmation of his moral standards, it is very difficult to judge how far Christianity has really been assimilated into Baganda culture.'[2]

In another area, Malaita, in the Solomons, Christianity is firmly rooted probably owing to certain similarity with the heathen past. Still it has caused disintegration in several aspects of native social life. Christian schools are responsible for the impudence and laziness of the students. The children no longer respect their parents and help them in their leisure hours but merely play and roam about for long hours after the lessons are finished. Attempts to stop it have proved futile. Dr. H. I.

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[1] L. P. Mair—An African People in the Twentieth Century, p. 3.
[2] L. P. Mair—*ibid.*, p. 261.

Hogbin who studied these islanders informs that young people in mission areas develop interest in sexual matters at an earlier age.[1] He records a number of cases of sexual unchastity among young folk leading to premarital pregnancy. 'Nowadays when an intrigue is discovered the teachers and parents usually insist on marriage of the couple'. But older people are horrified and chafe at being prevented from killing the delinquents.

We are ready to believe that the missionaries begin their work with the best of intentions but good will is not sufficient safeguard against unconscious or ill-judged measures. When you once let loose the forces of disruption there is no means of knowing how far they will go and when they will cease. Thus bride-price as an institution has received attention from the missionaries in the Solomon Islands. It has been prohibited as an evil custom among the converts. Dr. Hogbin writes 'I have myself heard a missionary deplore the fact that the natives have such little regard for their women as to buy and sell them like pigs. He was under the impression that the transfer of valuables gives the husband the right to treat his wife just as he pleases.' This is far from the truth. The parents of the girl who receive the bride-price do not hoard it for their personal use but distribute it among relatives 'so that if wealth flows out of the kinship group when the men marry it flows back again with the wedding of the girls'. But out of this transaction society in the Solomon is endowed with an important social control Belief in magic and ancestor cult, and payment for brides are the most effective sources of the authority of the elders over the youth. The Church in this particular area realized it too late and a compromise was effected in 1929, when bride-price was allowed but fixed at three *tafuli'ae* (approximately worth two pigs). But this has not solved the problem as the amount is too low and can be earned by any normal youngman who will not have to depend on his relations for this. Thus the new measure does not establish the institution at its original position.[2] Dependence of the youth on the aged is a strong link in the social management of Malaita and it cannot be destroyed without disturbing the other social traits which are linked with it. Polygyny is another institution which has met with the disapproval of the Church in some Melanesian Islands. The missionaries have even induced the Administration to prohibit it in particular areas. In the Trobriand islands [3] the prohibition of polygyny undermined the position of the chiefs by robbing them of the most important source of income and led to subversion of native authority and caused general disorder. This shows how even a perfectly

[1] H. I. Hogbin—Experiments in Civilization, p. 204.
[2] H. I. Hogbin—*ibid.*, pp. 212 and 213.
[3] Malinowski—Sexual Life of Savages, pp. 110 and 114.

desirable and beneficial measure from our standpoint may be injurious to a community with a different social system. These are only a few instances of such maladjustments brought about by missionary attempts. So far as regards well-intentioned attempts without a knowledge of the situation.

The motive which guides the Christian missionary as well as the realm of his duty and obligation are beyond the jurisdiction of scientific criticism but not so his methods. The missionaries have accumulated much anthropological knowledge but they have used it less. A distinguished missionary-anthropologist speaking of missionary methods writes that the 'missionaries have regarded themselves as agents of European civilization and have thought it part of their duty to spread the use of English language, English clothing, English music—the whole gamut of our culture. They have confounded Christianity with western civilization. In my opinion this is a mistaken view of the Christian mission. It is not his business to substitute European tribal customs for African or Polynesian.'[1] But unfortunately they have made this attempt in most of the places where they have been commissioned to carry the message of Christ. Charles Jhonson a distinguished missionary of Zululand—not an anthropologist—declared in unequivocal language how this method had been carried to the farthest extreme. He wrote 'the missionaries were the products of their time. The European consciousness of superiority to the Bantu was a very marked feature of that period .... No one tried, as far as can be judged, to learn what there was of good in the Bantu system of life and conduct, and to sublimate it by infusing Christian doctrine and ethics into it. The central idea was to prise individuals off the mass of the national life, rather than to leaven the whole nation with Christian teaching. When so prised off the individuals were gathered into missionary reserves and no longer permitted to take part in the life of their nation.' It is of course claimed that this criticism of a past age does not hold good for the present, nor for all regions. Unfortunately it is still applicable to India and this has been evidenced by no less a person than a provincial director of ethnography—himself a Christian Englishman and a high government official.

We are not in a position, at present to assess Christian missionary work among tribal people of India, as neither the Government nor the public have made any serious attempt to subject this kind of work to a systematic study by trained people. But the attempts of the Christian Missions among Harijan people have received some attention from political leaders and reports of their work have come out in the press. These, after

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[1] *J.R.A.I.*, Vol. LXIV, 1934—Presidential Address by Rev. E. W. Smith.

all, do not show them in a good light. It appears that the Christian Missions in their zeal for conversion have lost sight of their ultimate aim. They have misconstrued the means for the end. Instead of making it their life's work to carry the message of universal and eternal love to the suffering humanity which the Son of God was commissioned to bring to this world they merely spend all their energy in inducing people to go through the ritual of baptism. Such conversions are not the effect of a real change of mind brought about by true Christian teachings which claim to enlighten the soul and to satisfy its craving for eternal love and knowledge. On the other hand, they are occasioned by worldly inducements of momentary importance. The result is that the converts often flock back to their old fold as soon as the temporary need is removed. The very nature of these *en masse* conversions proves the truth of the above assertion and indicates the state of mind which induces such conversions. I shall give only two instances of this conversion for conversion's sake.

In 1936 a Roman Catholic Mission came to Arrah and began work. At first they tried to bring to their denomination the Protestant converts of the locality and were successful to a certain extent. But later they turned their attention to the Hindu Harijans. Their method is to visit a village and make themselves familiar with its inhabitants. Next they establish a school with a Harijan teacher who is either himself an influential man of the locality or has an influential relation there. Thus they bide their time until a tension ensues between the Harijans and the other inhabitants of the village or a litigation starts between the two groups. Then they side with the Harijans, give them money and advice. 'They are thus hailed as saviours and conversion follows as if to repay the obligation.' In thana Piro they converted about 450 persons within a period of a little over one year. 'The one remarkable feature of these recent conversions is that they take place *en masse*. Whenever a village Harijan leader accepts the new faith almost all belonging to his clan follow him. Sometimes an influential Sardar is instrumental in converting people of his community living in several villages.' Such conversions were not due to convictions but to socio-economic reasons which were not far to seek. Success was due to the peculiar situation in which social disabilities and economic iniquities had disturbed the mental equilibrium of this oppressed social group.[1]

Here is another instance of such conversion. In Salem District during 1939 Harijans were being converted by the Christian Missions on a mass scale. The caste Hindus decided not to employ these converts during religious festivals or social ceremonies such as birth, marriage and death, or even in

[1] M. K. Gandhi— How they convert', *Harijan*, June 19, 1937.

agricultural works. This meant a substantial loss of income both in cash and kind to these converts. The result was that many of them sought reconversion and came back to their former fold. 'This is due no more to a change in belief than their first conversion was. Prospects of material gain lured them to Christianity; actual loss of employment compels them to come back. Thus during 1939 as many as 153 people from three villages have been reconverted here, while many were reconverted in other places ....'[1] These two instances clearly indicate the aims and methods of at least some, if not all, of the Christian Missions working in India. Another significant fact about Christian missionary work in India is its utter failure among the middle and the upper classes. This shows its weakness. It is not conviction which attracts people to Christianity but lure of worldly gain. Africa also testifies to this fact and anthropologists working in different parts of that continent have repeatedly attracted our attention to this feature of Christian conversion.

Christianity has been adopted by subject races when it has been presented to them by members of the governing nation, not because of its inherent merits but because of its material advantages. The white man's wealth and his mechanical mastery over natural forces produce a sense of inferiority and dazzle eyes when first viewed. When they realize that the way to this wealth is through the school they assemble at its door and begin to devour without discrimination whatever is placed before them. 'In the light of new knowledge the old traditional life is easily despised. The ancient language appears barbarous .... Old customs, old loyalties are thrown overboard.' To what an extent this systematic donationalization runs can be gathered from the fact that in certain parts of Africa 'not a single African leader considered it possible for anybody to be at once a Christian and an African'. If this be the real position, it is now time to stand and reckon whether this vast amount of wealth in men and money can be employed in a better and more profitable manner.

Fortunately, we hear, there is a change in the attitude of the missionaries at least in other countries. They have realized the existence of valuable traits in native culture and are now trying to make a synthesis of European and local cultures through the schools and missions. This new attitude demands closer co-operation with anthropology. Sublimation of local traits needs careful research into the nature of local institutions and beliefs whose essence is proposed to be conserved in the new synthesis. This, no doubt, pushes the missionaries into the embrace of the anthropologists for help in discovering the vital elements of culture. Already the Protestant missionary societies

[1] M. K. Gandhi—*Harijan*, January, 27, 1940.

have established their own Department of Social and Industrial Research. The International Institute of African Languages and Cultures owes its origin to a group of missionaries and their friends. Missionaries on furlough now attend lectures on anthropology and already there are in the field a number of academically trained anthropologists in the service of the different Missions. Dr. Hogbin of Sydney University wrote in 1939 that 'the Department of Anthropology in the University of Sydney during the last few years has trained over seventy candidates for the mission field in New Guinea, Papua, Fiji and Australia.' [1]

I wish to attract here the attention of our Indian missionary organizations especially those which are engaged in work among primitive tribes. They are to take lessons from their compeers of the other faith. They also may fall into the same traps which have proved ruinous to their Christian brethren. No doubt they are nearer to their subjects in colour, faith and social values. There is of course no abrupt break between the primitive and the advanced in India; one gradually merges into the other through the intermediate grades of the so-called exterior castes. This is to their advantage as it helps them to realize the mental make-up of the primitive more easily. But this should not lull them to security. There are innumerable pitfalls and they must be armed with knowledge to avoid them. We have already stated that most of the Indian organizations are worked by men who have shouldered the task out of sheer love and sympathy for the suffering humanity. They have not been attracted by any hope of emoluments. But this condition cannot and will not last for ever. A time will come when paid workers have to be employed for this type of work. But as it stands at present we have the unique opportunity to utilize this army of self-sacrificing spirits for the purpose of social service throughout the country. The material is no doubt good but it requires proper moulding and this can be accomplished if our Universities take up the task. Training is necessary for every kind of work and social service is no exception. The Universities by opening Social Service Classes under suitable teachers and by providing for instruction in a number of subjects such as rural hygiene, rural sanitation, adult education, co-operation, village industries, etc., with anthropology at their forefront, may give a new orientation to this branch of our national activities.

Anthropology and Administration

The importance of anthropological knowledge in administrative affairs is recognized nowadays by different countries especially by those with a section of tribal population. In India, according to the last Census operations, we have a tribal

[1] Dr. H. I. Hogbin—Experiments in Civilization, p. 249.

population of more than 22 millions out of a total population of a little over 352 millions or in other words out of every 16 persons one is an aboriginal. These people occupy the most inhospitable regions of our country. Their habitat extends over deep forests and steep hill ranges where they eke out a miserable existence. Away from the ken of civilized men and unaware of them these children of nature silently fight with inhospitable environment and wrest from it the barest minimum necessary for keeping body and soul together. They have no idea that the State has any responsibility towards them or that their poverty is in any way connected with the activities of their more prosperous neighbours. They attribute their ill fortunes to the machinations of evil spirits and remain satisfied with making offerings to them. But their ignorance is no excuse for us. The Government of the country as well as the educated public have no justification for shutting their eyes from the miseries of these simple people. We have both legal and moral responsibility for these 22 millions of wretched souls. In India, the aboriginal tribes have to face two sets of exploiters: there are the foreigners to whom every Indian, whether savage or civilized, is equally exposed, and besides them there are the advanced Indians, who have established themselves in various capacities in the midst of the aboriginal population and are advancing their own interest at the expense of the savage. The Indian aborigines thus require double protection—protection from both internal and external exploiters. This has been acknowledged, in theory at least, by the British Parliament. The Government of India Act, 1935, provides (in Sections 91 and 92) for declaring these tribal tracts as 'excluded or partially excluded areas' and they have been placed under the direct charge of the Provincial Governors. Such areas are free from the jurisdiction of the ordinary administrative machinery as well as the Provincial and the Central legislatures. This means a different administrative system intended to provide protection to the aborigines from the representatives of the internal exploiters. But it has not saved them from the foreign exploiters. Moreover, the type of administration set up for these areas does not differ much, in essence at least, from what was in existence in the past or what we find outside these areas at present. These are half-hearted measures which look well in administrative reports but do not help much in actual life. The inadequacy of these measures will appear from a comparison with the steps taken in other parts of the world as for example in Africa, to improve the condition of the tribal people.

In Africa the European nations have come in intimate contact with the tribal people and an experiment of great magnitude and of immense human interest is going on there in the matter of administering the aboriginal population. A

brief reference to this may give us some idea of what possibly can be done in India in the same sphere with necessary alterations. 'The central problem which faces Government in East and Central Africa is to discover a basis on which white and black, with Asiatics as well, can live together under conditions of rapid economic change and with adequate opportunities for political development.' The policy of Parallel Institutions provides according to a large number of thinkers the best solution of the problem. This policy is often known as Indirect or Dependent Rule. It has been long perceived in Africa that under Direct Rule, the tribal organizations with their customary laws and traditions either gradually disintegrate or are forced underground where they tend to take the form of anti-governmental organizations and secret societies. This led to a change from Direct to Indirect Rule which was initiated from the beginning of this century. As a result, the greater part of tribal Africa is now being administered on this principle. What are the essential points of this Indirect Rule? In the language of Miss Margery Perham 'it is a system by which the tutelary power recognizes existing African societies and assists them to adapt themselves to the functions of local government.' It aims at developing local institutions under advanced guidance. It does not intend to keep them in a static condition but wants to develop them within the framework of native society so that they may conform to civilized standards. Now, this policy of Indirect Rule cannot be applied to administrative activities alone. If it is to be successful it must be applied simultaneously to other spheres as well such as social organization, education, religion and economic affairs.

What is the relation between this new policy and anthropology? In one word it may be characterized as an experiment in applied anthropology. Though it will be too much to claim that the policy of Indirect Rule in Africa originated from anthropological knowledge, it is clear that its extension has been preceded by wide anthropological research on which it was certainly based. To take an instance, in Northern Nigeria officers were required to come in close contact with the natives and collect materials on their life while preparing the tax-roll. Rev. E. W. Smith, once President of the Royal Anthropological Institute, referring to this custom writes—'The material thus collected formed the basis of the policy of government which sought to work with and for, and not against, the natural and national evolution of the peoples. So it was found possible to extend Indirect Rule to pagan communities whom few at one time would have expected to be susceptible to this mode of government. In later years efforts have been directed to establishing the same system in the southern provinces of Nigeria after painstaking investigations into the indigenous forms of clan or tribal control. In the Anglo-Egyptian Sudan, Gold Coast, Northern Rhodesia

and Nyasaland it has also, in varying degrees of completeness been instituted.' After the Great War this system was introduced into the mandated territories under Britain where a consistent and patient attempt was made to resuscitate the indigenous mode of government. This is the story of Cameroons, Togoland, and Tanganyika Territory.

How far and in what manner anthropological knowledge can be applied to problems of tribal administration has been experimented upon among the Hehe tribe of Iringa District in Tanganyika Territory for a period of one year. The District Officer Mr. Bruce Hutt referred his administrative problems to Mr. G. Gordon Brown the anthropologist who had been conducting anthropological field-work among the tribe for some time past. They followed the principle laid down by Prof. Malinowski that 'the practical man should be asked to state his needs as regards knowledge on savage law, economics, customs and institutions: he would then stimulate the scientific anthropologist to a most fruitful line of research, and thus receive information without which he often gropes in the dark'. They decided to collaborate on the basis that the administrator will make practical decisions on the information supplied by the anthropologist on whom he will fully rely as to the accuracy of the information. The latter also, on his part, would not question the decision of the administrator in case of a difference of opinion provided all the informations have been laid before him. The result of this experiment was published in the form of a book called *Anthropology in Action: An experiment in the Iringa District of the Iringa Province, Tanganyika Territory* in 1935 and shows how successfully anthropological knowledge can be applied for administrative purposes.

The works of the Fellows of the International Institute of African Languages and Cultures have proved beyond doubt the value of anthropological knowledge in practical administration. The Report presented to the Rockefeller Foundation on the work of this Institute (July 1, 1931—June 30, 1939) claims that 'The Governments, indeed, of some of the territories in which the Fellows have worked have shown themselves anxious to obtain their further services'; that Dr. Margaret Read has begun 'a study of the effects of the emigration of adult males on village life' in Nyasaland at the request of the Government; and that Dr. S. F. Nadel has been appointed Government Anthropologist in Anglo-Egyptian Sudan and is at present working in the Nuba Province. The Government of Northern Rhodesia 'set up in 1937 the first institute for systematic sociological research in colonial Africa', though its formal inauguration has been deferred till 1940. This is the Rhodes-Livingstone Institute with its headquarters at Livingstone. The government supplies 52 per cent of its funds while the rest is derived from munificent donations from commercial and industrial

organizations. Already two anthropologists are working under this Institute in Northern Rhodesia and more will be appointed with the increase in funds. The same Report states 'The Fellows have been asked for advice on special subjects by the Governments of the territories in which they were at work. To give some examples, Dr. M. Fortes was asked by the Government of the Gold Coast for a report on marriage law among the Tallensi, and he also prepared a plan for the new constitution for the Tale Native Administration, which became the basis for the constitution introduced in 1936. In Nigeria Dr. Nadel was consulted on a number of subjects.' He advised the government about the 'traditional system of village political organization among the Nupe and the possibility of using it for purposes of modern administration. He also dealt with questions relating to the adoption of special pagan courts in addition to the existing Muhammadan courts of the Emirate, the reorganization of the town administration of Bida, the earning power and income of the inhabitants of Bida in connection with a reassessment of taxation which was contemplated, and questions of agricultural technique as they affected a Government scheme for introducing mixed farming. Dr. Wagner was asked by the Government of Kenya for advice and information on problems of Kavirondo land tenure ....'

The same intimacy between anthropology and administration has been demonstrated from another quarter. The work of Dr. Raymond Firth in Tikopia, a small island in the Pacific with a population of twelve hundred souls, shows how the 'traditional equilibrium between population and food supply was maintained, among other things, by "a celibacy in which chastity was not enforced", by "a discreet infanticide", and by war'. Now this equilibrium has been upset by the Christian missionaries and the government. The former by discouraging premarital sexual intercourse has introduced earlier marriage leading to a greater number of progeny and the government have prohibited infanticide and war. Dr. Firth predicts overpopulation and famine at the end of another generation, if not earlier, if this rate of increase continues. Thus the Government is forewarned one generation ahead and it is the duty of the State to be forearmed. Dr. Firth points out in the same connection what alternative measures might be adopted such as agricultural development, migration, encouragement of birth-control, showing at the same time the inherent difficulties in each case. Thus the anthropologist has amply justified his claims about the value of technical information for governmental purposes.

We in India are also faced with the administration of a huge tribal population and with the advent of popular government, it is high time to move in the matter and see what improvement is possible in India. For this, at the first instance, a

thorough anthropological survey by specialists is necessary. This is to be followed by employment of officers with anthropological training who will keep themselves abreast with the changes in the cultural make-up of the people over whom they are placed and thereby keep the records of the specialists up-to-date. This is equally necessary for tribal and non-tribal areas. As a rule all officers of the State to be employed in the tribal areas should have either previous anthropological training or arrangements should be made to give such training after appointment in or transfer to such tracts. This rule is to be observed not only in connection with executive and judicial officers but also with those who belong to the police department and forest service. In fact, the Government is required to create a band of officers specially fitted for this type of work by education and inherent sympathy. They should not allow things to drift. The force of this argument may be brought home by reference to the many cases of bungling caused by lack of anthropological knowledge of the officers employed in tribal areas but owing to lack of time I desist from them at present. It is not, however, my intention to cast any aspersion on the ability and sagacity of the officers concerned at present with the administration of tribal people but there is surely sufficient scope for improvement in this particular sphere of activity. If the different Provincial Governments can be persuaded to adopt this policy, it will, diminish the chances of maladministration. This has been done in the case of Africa where it has proved successful and there is every chance of this policy becoming successful in India too.

Conclusion

So long our picture included mainly the primitive or the backward peoples. But anthropology is not concerned with them alone. The Functional School of Anthropology has demonstrated without leaving any scope for doubt, that it can be applied with equal force in solving the problems of civilized life. Anthropology is no longer concerned with the savage only: it has passed that stage.

India is at present passing through a transitional period not only in politics but also in its social, religious and economic affairs. We are confronted with queries at every turn. The politician, the social reformer, the economist and the religious enthusiast—every one of them is required to solve new problems. At this critical stage of our national life a minute analysis of our culture based on facts collected from all possible sources would be of immense help to the former. They will know what we have and this will help and guide them to formulate new ideas and ideals and new paths in their respective spheres. Now, this analysis of culture can only be undertaken by trained anthropologists, who are best equipped to do it. This further

broadens our field of activity. Problems like female emancipation, dismemberment of the joint family, dying out of the artisan castes and decay of the middle class—to mention a few only—are causing anxiety to the best minds of India. Each and every one of them is a vital question affecting the whole social organism and they should not be left to amateurs and enthusiasts for solution but should be tackled by properly trained scientific men. Here we have the glimpse of a wider horizon of activity for the anthropologist who may thus serve the State and his society, and prove himself to be an indispensable adjunct to modern life. This is to my mind the highest realization of the Science of Man.

SECTION OF
MEDICAL AND VETERINARY RESEARCH

President:—A. C. Ukil, M.B., M.S.P.E., F.S.M.F.B., F.N.I.

Presidential Address

(*Delivered on Jan. 6, 1941*)

SOME ASPECTS OF PUBLIC HEALTH IN INDIA

'Man hardly realizes that he can shape his own destiny'—
Bergson.

A historical perspective

From the earliest times man has been actuated by the instinct of self-preservation and the natural impulse of life-interest and life-protection which has been expressed in various ways, such as the raising of food by agriculture and its storage, shelter, water-supply, land drainage, irrigation and removal of refuse. The occurrence of disease in individuals led them to evolve certain empirical rules of personal hygiene and the urge for herding together induced them to evolve and utilize health services according to their concept. For example, the recent excavations at Mahenjo Daro and Harappa in the Indus Valley and the Punjab have shown that, as far back as 3500 B.C. or even earlier (pre-Aryan civilization), the people of those days had an astonishingly high level of sanitation. Not only were there bath-rooms in the private houses with water-proofed brick floors and house latrines but a system of drainage with socketed drain pipes was provided by which the sewage was carried into street tanks and thence removed by scavengers. Sir John Marshall notes that every street, alley-way and passage had its own covered conduits of finely-chiselled brick laid with great precision and that the whole drainage system was extremely well developed. It has to be remembered that the Bronze Age peoples of England at this time were living in small grass or mud-covered huts. Civilization in Europe in the sense that we know it was a much later affair than in these parts of India and Egypt.

Then came the Vedic period of Hindu medicine (about 1500 B.C.), which attained its highest development between 600 B.C. and 200 A.D. The available literature shows that considerable progress was achieved in anatomy, major and minor surgery, internal medicine and pathology, midwifery and children's diseases, hygiene and toxicology, and elixir (internal

secretions) and sexual hygiene. Hospital services, both for men and animals, existed and nursing services were utilized. There were excellent rules of personal hygiene and some of community hygiene. Castellani has noted that at Anuradhapura in Ceylon a sanitary officer was stationed to look after the health of ten villages. But the palmy days of this civilization gradually receded, and although attempts were made to conserve the knowledge which already existed the eastern savants gradually became speculative and bound by traditions. The period between the 2nd to the 15th century was a very dark period for the science of medicine, more particularly in Europe.

The contributions of Hippocrates, Alexandrian School of thought and Galen led to the foundation of Greeko-Roman Medicine in Europe. Gradually since the middle of the 15th century, the work of Vesalius, Paracelsus, Fracastoro, Malpighi, Harvey, Leewenhoek, Sydenham, Ramazzini and others laid the foundations of modern medicine. Meantime plague and pestilences repeatedly overran Europe owing to the lack of knowledge regarding the nature of disease. its causation and propagation.

The Scientific Renaissance in the 18th century in other fields, viz. chemistry, geology, botany, zoology, physics, mathematics and astronomy, made a deep impression on the learned world. In the field of public health, workers were just beginning to wake up and the medical history of the century was crowned in 1798 by the discovery of vaccination by Edward Jenner. Besides the development of the scientific spirit, an extraordinary reaction to the new conditions of life was noticeable in this period, viz. the growth of a new motive of humanitarianism urging the inner man to ameliorate the condition of the stricken and the less favourably placed people in society. No doubt this was fostered by the liberalism of the French Revolution and the writings of Voltaire, Bentham, Howard, Adam Smith and others. Private philanthropy came forward and made it possible for the establishment of numerous hospitals.

The application of steam power to factory uses in 1785 in England brought about the Industrial Revolution, which led to a radical transformation of social and economic life in Western Europe. The demand for labour gave rise to congestion and overcrowding, particularly in industrial areas. Inertia of sanitary authorities, vested interests, ignorance and public apathy accounted for appalling conditions of sanitary neglect. The sanitary condition of London in 1842 and that of New York in 1865 and the sanitary consciousness of their inhabitants can very well be compared with those of many Indian towns of to-day.

The beginning of the 19th century was marked by the dawning of social consciousness in Western Europe. England, because of its pioneer industrial developments, serves as a prototype to illustrate the social evolution paralleled in other

countries as they became industrialized. Widespread insanitation, repeated invasions by smallpox, cholera and plague, the gradual worsening of the working conditions of factory labour following rapid industrialization and the abounding miseries of the poor, social discontentment and a universal desire for amelioration led to the efforts of Chadwick and Simon to enquire into, report and press for public health reforms. Although the beginnings of environmental sanitation had already taken place, there was not a single comprehensive Act of Parliament concerned with the health of the people until 1845.

The Reform Act of 1832 gave franchise to one million citizens and the passing of the first Public Health Act of 1848 coincided with the maturation of social consciousness. Organized sanitation started with efforts to improve poor relief, public vaccination, drainage, water-supplies, burial reform, registration of births and deaths, and sanitary legislation.

The evolution of the experimental method rescued medicine from the clutches of magic, religion, guess work and quackery. The outstanding discoveries of the 19th century regarding anaesthesia, antiseptic surgery, the causation of infective diseases and the principles of immunology, along with the advances in chemistry, physics, physiology, pathology and pharmacology swept through Western Europe like a whirlwind and led to an increase in the knowledge of the diagnosis, prophylaxis and treatment of diseases These fundamental advances established Hygiene and Preventive Medicine on a firmer basis and made it practicable, although there has always been a lag between scientific discoveries and their application. In the sphere of education, the advent of public education in 1870 became one of the great public services. The need for the abolition of quackery and the realization of the idea that an effective public health reform needed an enlightened and organized medical profession led to the passing of the Medical Act of 1858 and the establishment of the General Medical Council to regulate medical education and to control the publication of the State Pharmacopoeia. The advent of an organized medical profession, the public medical services and of post-graduate medical education also took place during this period. The Royal Sanitary Commission of 1869 laid down, under eleven heads, the national sanitary minimum of 'what is necessary for civilized social life in every locality' laying emphasis chiefly on the environmental services. Further political and economic progress facilitated the way to sanitary reform and social welfare. The demand for hospital isolation, extension of hospital accommodation, the reduction of poverty, the increase and control of food supply, the prevention of industrial diseases, the improvement of housing and working conditions in the factory, the education of defective children and the care of the insane were pressed forward.

After the industrial revolution and before the discoveries of microbiology, bad hygienic conditions in the environmental sphere were attended to more by architects, engineers and chemists than by physicians. As a result, insanitary dwellings were demolished and replaced by better ones, wide roads and parks were designed, water pipes and sewers laid, abattoirs were built, schools and public baths were constructed and measures taken against the adulteration of food. The beneficent result of these environmental services is reflected in the percentage reduction of mortality from tuberculosis in England from 100 to 70 by the time the tubercle bacillus was discovered (1882). Since the discoveries of the bacterial causation of infective diseases and the increasing knowledge of the principle of natural and artificial immunity against these diseases, the shotgun empirical methods of preventing infection of earlier days were replaced by precise methods of controlling infection conveyed through water-supplies, insect bites and direct contact. These researches were continued through the succeeding years of the 20th century leading to a fuller knowledge of the physiology of man's body in relation to his environment, further advance in the control of infective, tropical and parasitic diseases, remedial measures against nutritional disorders and disturbances of internal secretion and the development of chemotherapy against microbial diseases.

The establishment of the Medical Research Committee in 1913 and the impetus given to it during the last Great War led to the formation of the Medical Research Council in 1920 and of institutes for the study of local and tropical diseases, thus making it possible for the extension of medical research on various national health problems and its application by the individual, the community and the State.

These scientific advances enabled a fuller apprehension of positive health, heralded the emergence of sociological medicine and profoundly affected the action and purpose of statecraft. Political and economic advance was followed by legislation and state action on the improvement of working conditions and occupational hygiene, school health including the provision of school meals and preventive treatment of defects, the prevention of maternal and infant mortality, health, unemployment and invalidity insurance, immunization against disease, the provision of better and safer food, and the prevention and care of mental deficiency, tuberculosis, venereal diseases and cancer. Subsidized housing and town-planning schemes made it possible for the eradication of slums, the construction of sanitary dwellings, the provision of cheap-rental houses and the abatement of overcrowding, resulting in a great improvement in sanitation and cleanliness. The advent of social emancipation since 1919 speeded up the reforms in every sphere. Finally, the creation of the Ministry of Reconstruction resulting in the formation of

the Ministry of Health, linked the central government to the corporations, councils, counties and districts and ensured a better co-ordination in the application of the principles of social welfare between the different departments or agencies. The difference between preventive and curative medicine was fast vanishing.

The requirements of the new situation needed a variety of institutions and a large category of personnel to look after them—doctors, technicians, specialists, nurses (public health, school health and institutional), chemists and auxiliaries (masseurs, radiologists, dispensing opticians, etc.)—by bringing clinical and non-clinical subjects closer to each other. Medical education had, therefore, to be reorganized and by 1930, 27 medical schools were engaged in turning out general practitioners, besides several institutions for post-graduate teaching. The present number (1939) of medical practitioners in England and Wales is 62,000 (or one doctor to 800 people), of whom 16,800 are panel practitioners looking after 17 millions insured at a cost of £8 millions. There are 1,400 Medical Officers of Health under the local authorities, 5,000 connected with the Poor Law Service, 500 tuberculosis officers, 110 venereal officers, 3,000 attached to maternity and child welfare centres, 2,000 on the Post Office list, 1,700 examining factory surgeons, 1,400 employed in the school medical service and 16,800 insurance practitioners. Over 2,700 hospitals with nearly 300,000 beds, including 10,000 maternity beds, are looking after curative medicine in a population of 50 millions. Every school week in the year the children from 100,000 homes are medically or dentally examined.

The cost of treatment and maintenance of sick persons amounts of £185 millions a year. The public expenditure on the preventive services or prevention of ill-health is £13 millions a year, while the public environmental services which largely contribute to good health cost £100 million a year. There has been a general desire for bringing the advantages of medical knowledge adequately within the reach of people, but the increasing complexity of modern health organization and the increased cost of treatment still render it difficult for many citizens to pay for the full range of services. This accounts for the delay in the treatment of disease. It is estimated that the economic loss caused by ill-health in England to-day still amounts to £300 million a year. Preventive health and social services and medical attention are still considered to be grossly insufficient.

The increasing significance of the social services is indicated by their expenditure. The total expenditure and the expenditure per capita had risen in Great Britain from £5 millions or 5*s*. per head in 1850 to £31 millions or 19*s*. per head in 1900 and to £400 millions or £8–17*s*. per head in 1934. The expenditure on Medical Services, exclusive of Mental, rose from £1½ million in 1900 to £17½ millions in 1934. Although acute diseases have been

largely controlled, many chronic ailments still baffle scientific workers and administrators.

In 1838, the crude death rate in England was 22 per thousand of population, in 1937 it was 12 per thousand. In 1838, the expectation of life at birth was 40 years for an English boy and 42 years for an English girl; in 1932, it stood at 58 years for a boy and 62 years for a girl; in other words, in 94 years the probability of life had risen by 18 years for a boy and 20 years for a girl. The spectacular decline in the incidence of some diseases, consequent on the application of available knowledge and co-incident social evolution is illustrated in some of the curves given below. The position of India in this regard is also indicated therein and by figures.

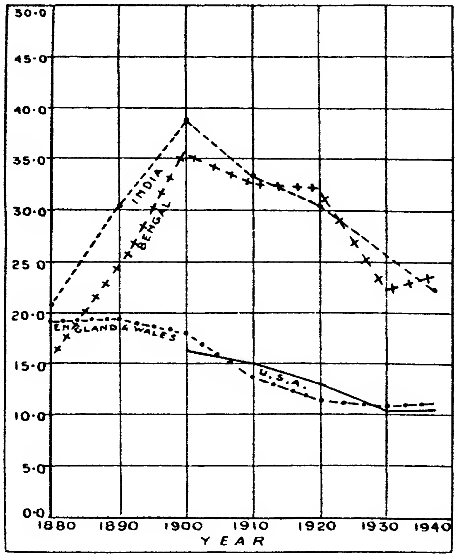
Modern Public Health—a field of social activity

Prof. Winslow of the Yale School of Medicine (1920) defines Public Health as 'the science and the art of preventing disease, prolonging life, and the promoting physical health and efficiency through organized community efforts for the sanitation of the environment, the control of community infections, the education of the individual in principles of personal hygiene, the organization of nursing services for the early diagnosis and preventive treatment of disease, and the development of the social machinery which will ensure to every individual in the community a standard of living adequate for the maintenance of health'. Social conditions react on health and health reacts on social conditions.

Bernal (Bernal, J. D.—The Social Functions of Science, 1939) goes so far as to say that 'it is probable that an overwhelming majority of diseases that occur throughout the world are due directly or indirectly to the lack of primary necessities, generally food, and many of the remainder are attributable to bad working conditions'. Considerations of health can seldom be divorced from economic, demographic and social factors. The human factor is the more important than other factors in raising the resisting power to diseases of backward countries like India. Speaking on nutrition, Sir John Orr expressed the following opinion in his Chadwick Lecture in 1935—'It may be assumed that any Government would accept as the first essential the necessity for ensuring that every individual in the State shall be able to get a diet sufficient to maintain health. If a system of production and marketing of foodstuffs fails to do this, the State, through its medical and social services, must pay for the treatment of those suffering from an inadequate diet'.

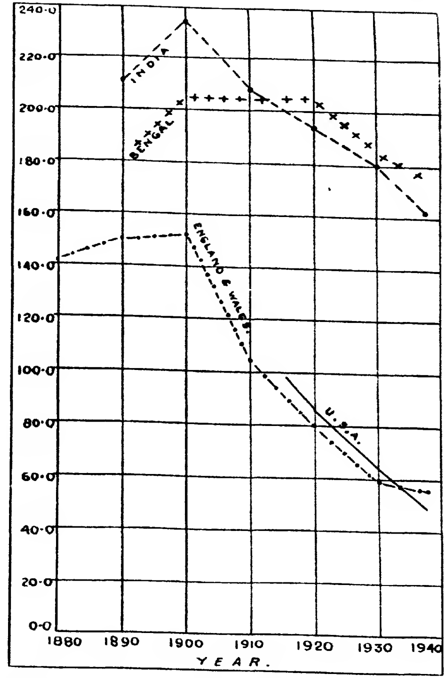
Medicine needs to recognize the whole nature of man, as shaped by his home, his surroundings, his education, his work, his economic status, his recreation and his struggles and aspirations. Medicine has thus become fundamentally a social science and a field of social activity in which is applied practically every

General mortality in England and Wales, U.S.A., India and Bengal—1880 to 1937. (Per 1,000 population.)



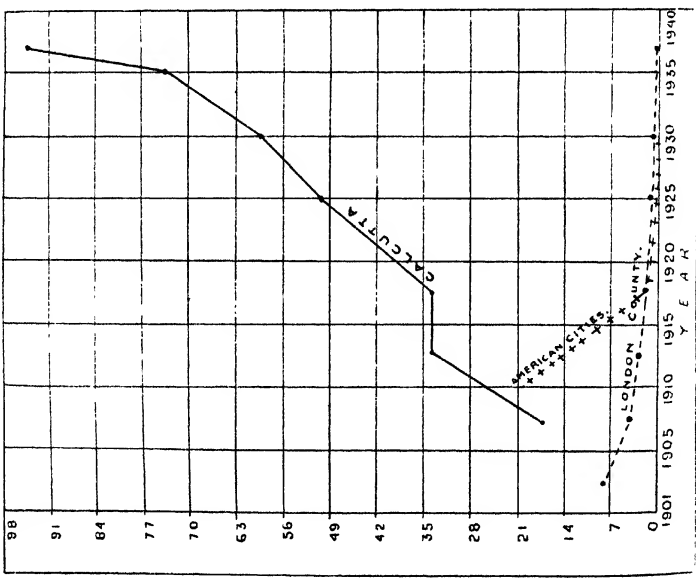
India and Bengal began in 1880 with nearly the same mortality rate, but at the end of 1937, while it has steadily declined in England and Wales and in U.S.A., the same cannot be said of India or Bengal.

Infantile mortality in England and Wales, U.S.A., India and Bengal—1880 to 1937. (Per 1,000 live-births.)

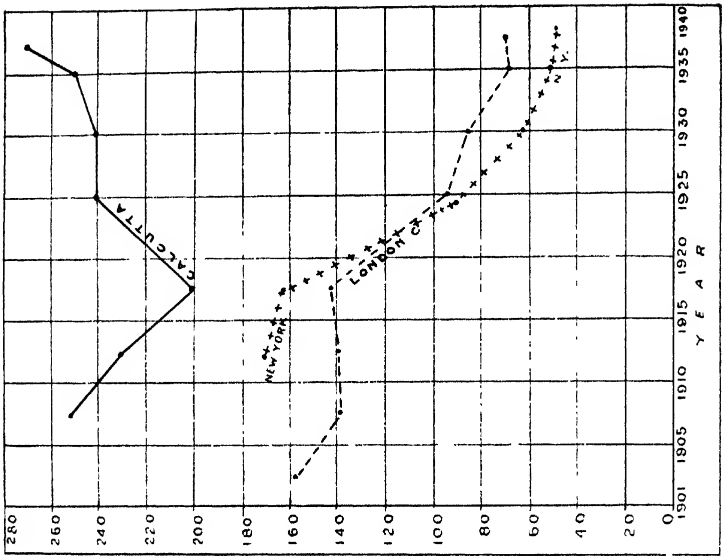


Since 1890, the reduction of infant mortality rates per 1,000 live-births in England and Wales has been at the rate of 20 deaths per decade, whereas in India the reduction has been at the rate of 10 deaths per decade during the same period. There has been hardly any reduction in Bengal.

Typhoid and paratyphoid mortality in Calcutta, London and American cities (average for 78 cities)—*1901 to 1937.* (Per 100,000 population.)



Respiratory tuberculosis mortality in (1901–1937) Calcutta, London and New York. (Per 100,000 population.)



Mortality figures for chief diseases in British India.

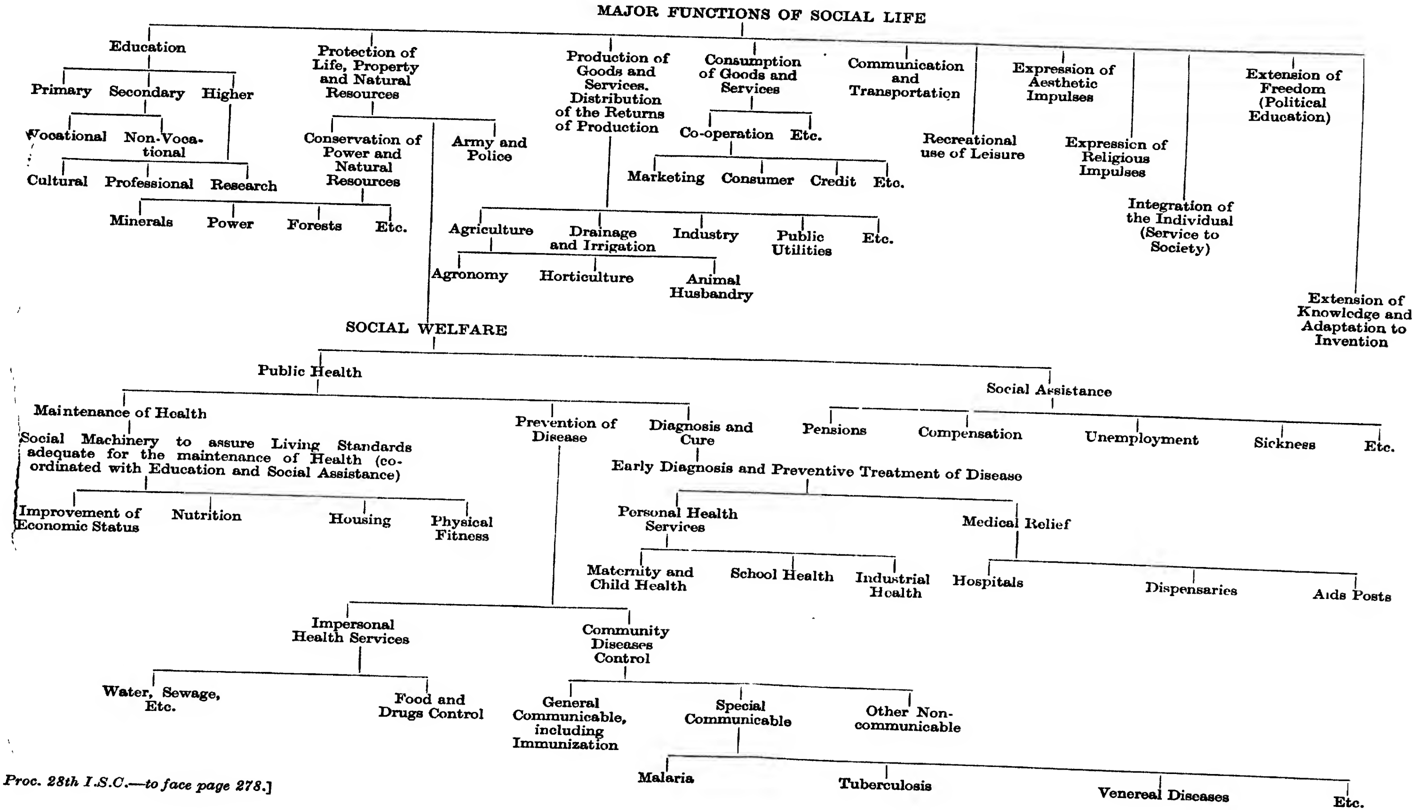
Diseases.	1900		1910		1920		1930		1937	
	Number of deaths.	Rate per 100,000.	Number of deaths.	Rate per 100,000.	Number of deaths.	Rate per 100,000.	Number of deaths.	Rate per 100,000.	Number of deaths.	Rate per 100,000.
Cholera ..	797,222	370	430,451	190	130,140	55	337,332	140	99,054	40
Plague ..	92,807	42·4	413,335	183	99,368	42	24,841	10	28,169	10
Small-pox ..	91,855	42	51,315	23	101,329	43	72,813	30	54,810	20
Fevers .. (Malaria, enteric, Kala-azar, and others.)	4,919,591	2,232	4,341,392	1,917	4,931,202	2,068	3,787,694	1,569	3,569,590	1,310
Dysentery and diarrhoea ..	530,654	241	267,672	118	218,734	92	237,892	99	267,479	100
Respiratory diseases (Tuberculosis, pneumonia and others.)	..	..	234,308	103	338,669	140	400,527	166	487,319	180
Leprosy ..	Not available.		Not available.		Not available.		Not available.		Not available.	
Crude birth rate (per 1,000) ..	36·06		39·52		32·98		35·99		34·5	
Crude death rate (per 1,000) ..	38·60		33·20		30·84		26·85		22·0	

basic science directed towards a comprehensive programme of community service. The following scheme is given to indicate the major functions of social life and the place which should be assigned to public health:

It will be evident that when maintenance of health and prevention of disease are aimed at in the programme of social welfare, the cure of diseases gradually becomes less voluminous in proportion to the rate of progress in the utilization of scientific tools for the physical, mental and moral well-being of the community. It is to be noted that here, as in many other spheres, scientific progress in the abstract has often out-distanced concrete achievement. The knowledge about the prevention and cure of many diseases and the maintenance of positive health and prolongation of life has been known throughout the world, but its application has lagged behind at different levels in different countries. The co-ordinated planning and technique of socialized medicine in Soviet Russia for 20 years have out-distanced the piecemeal achievements of England through 100 years. In Soviet Russia, the health of the individual is the concern of the State and of Society as a whole. Indeed, the Soviet Union is the one nation in the world which has undertaken to set up and operate a complete organization designed to provide preventive and medical care for every man, woman and child within its borders. Russia's example in the sphere of health protection has stimulated the Western European countries and America to consolidate their previous disjointed efforts into a cognate whole towards the ideals of sociological medicine.

'The failure to establish scientific methodology in determining tools for community welfare is one of the chief factors responsible for the present social lag throughout the world' (J. B. Grant). In public health administration, as in laboratory experiments, the principle of 'observation of natural phenomena and their confirmation through controlled experimentation' should be followed. Research, surveys and social experiments must be carefully blended in evolving the method of approach to a public-health-social problem. The evolving of practical methods requires sound economic considerations and proper training of the necessary personnel and their organization requires adherence to sound administrative principles, the securing of popular response and intelligent participation as well as the co-ordination of the inter-related spheres of governmental activity. Planned co-ordination between research, training and administration is an essential desideratum.

The essential *principles of sound public health administration* refer to (i) the necessity for the administration of the different health functions being undertaken for the whole community by a single governing body and not for different sections of the community by several governing agencies, with necessary co-ordination between inter-related sections; in other words, there



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should be 'centralized direction and decentralized activity'. The administration must provide for technical supervision and periodic appraisal of the efficiency of the organization. (ii) Successful administrative procedure results only from scientific investigation and demonstration of organizational methodology in the measures whereby knowledge can be applied in practice to groups of population. The proper training of the necessary personnel in applying the methodology is an important requirement. (iii) Successful administrative procedure must be based upon sound financial considerations and practicable economic budgetting suited to the area and the population. Where cash purchase of health reform is difficult, the available cash may be utilized for technical guidance and supervision and the citizens may be encouraged to offer trained voluntary labour (= payment in kind), which is the largest item in cash purchase. (iv) Successful community utilization of knowledge for public health reform and medical protection requires a certain level of politico-economic progress and education. Health of the people is achieved through the people being themselves possessed of adequate education in, and practice of, health knowledge. (v) The securing of co-ordination between the related spheres of social services, owing to their mutual inter-dependence. (vi) In order to ensure better working and to avoid mistakes in local effort, *the whole design* of a public health planning must be before the mind from the beginning. Any effort, however small and localized, can confer benefit, if it is designed in relation to the scheme as a whole.

The trend of Public Health Progress in British India

It is needless to point out that political events and social deterioration disorganized the systems of Indian Medicine even before the European powers came into touch with India. By 1800 A.D. the British were firmly organized as the rulers of this sub-continent.

The beginnings of the Indian Medical Service may be traced to 1600 A.D. when the Company brought in British doctors as ship's surgeons. Between 1763 and 1766, a regular service was created and was divided into civil and military. These doctors, who had to work under great difficulties, carried the torch of Western medical science from place to place. Assistants were at first trained as dressers, apothecaries and general hospital helpers—the fore-runner of highly trained subordinate services of later times. The first Medical School was opened in 1822 and a Committee on Medical Education was appointed in 1833 which led to the establishment of two Medical Colleges in 1835. The qualifications of the latter were recognized by the Royal College of Surgeons, London, in 1845. We do not find any noteworthy

progress in the first half of the 19th century except in the introduction of Jennerian vaccination in 1803 and the passing of the Indian Quarantine Act, 1825. The British rulers at this time were more concerned with the health of the army and of the Europeans in India. There was no evidence of any repercussions of the progress of scientific knowledge on the economic progress, the dawning and growth of social consciousness or the experiments in environmental sanitation.

The very active period of fundamental advances in science in Europe in the second half of the 19th century and the concomitant political and socio-economic progress which helped to establish hygiene and preventive medicine on a firm and practicable basis had rather poor repercussions in India. In the sphere of research, which was entirely in the hands of the British workers, half a dozen names stand out prominently, viz. Lewis (1872) described *Filaria sanguinis hominis* and *Trypanosoma lewisi*, Vandyke Carter (1877-78) described the causative organism of Indian relapsing fever, Evans (1880) described *Trypanosoma evansi*, Cunningham (1885) described certain bodies in Delhi boil which were later confirmed by Leishman and Donovan (1903) as L.D. bodies, Koch (1883) confirmed the identity of *V. cholerae* in Indian cholera, Haffkine (1895) introduced cholera vaccine and Ross (1897) discovered the transmission of malaria. The major part of our knowledge in the scientific sphere in India up to the end of the 19th century was due to the work of a few scientific departments of the Government and of a few isolated workers who devoted their spare time to pursuits which interested them. In quite a number of cases such devotion to work was discouraged by the heads of departments, as happened in the case of Sir Ronald Ross. Since all the important posts were held by British members of the Imperial Service, Indians got very little opportunity for working into the mysteries of the causation of diseases and the problems of their prevention and treatment. The first Pasteur Institute was opened at Kasauli in 1893 and the Haffkine Institute was started in Bombay in 1899 for the manufacture of prophylactic vaccines against cholera and plague. The Imperial Veterinary Research Institute was established in 1893. The Indian Institute of Science at Bangalore, which is now taking a prominent part in biochemical investigations, was started in 1896. Antiseptic surgery was introduced between 1876 and 1881.

In the sphere of education, the first three universities were founded in 1857 but these and others founded later were mainly of an affiliating type rather than serving as centres of teaching and research. The medical teaching was chiefly controlled by the Indian Medical Service, although loosely connected with the Universities. State medical services were composed of military and civil officers, besides a growing independent medical profession and the followers of the ancient systems of Ayurveda

and Unani. 47% of the officers in the Indian Medical Service numbering 220, which was treated as War Reserve, were posted to the civil side, all the important teaching and administrative posts being statutorily reserved for them. In the sphere of public health; as has been stated before, most of the efforts were chiefly directed to the safeguarding of the health of the army and the Europeans in India and to the prevention of infection through transport channels, land or water. It is said that the 'real history of sanitary organization in India' began in 1859 when a Royal Commission was appointed to report on the sanitary state of the *army* in India. This Commission suggested the appointment of a Commission of Public Health for each presidency 'to give advice and assistance in all matters relating to public health and to exercise supervision over the sanitary condition of the population, both European and Indian. 'The primary object of these provincial commissions was to try to diminish sickness in the army; but this was recognized to involve (1) the sanitary improvement of Indian towns, (2) the prevention and mitigation of epidemic diseases, (3) constant observation of the sanitary condition of the population and the reports of the prevalence of sickness, (4) the construction of works of drainage and water-supply, (5) the proper carrying out of sanitary rules and regulations, (6) the preparation of codes and rules adapted to the special sanitary requirements of the army and of the civil population, and (7) the submission to the Government of India of plans for co-ordination and supervising the whole sanitary administration of a presidency.' No doubt the rapidly advancing sanitary progress in England at the time and the occurrence of excessive disease and deaths in the army dictated the inception of these ideas, but it is significant to note that the Government of India at that time 'did not favour a general sanitary system owing to the financial and administrative difficulties of introducing this into India'. The following are some of the important public health Acts of the period:— Indian Lunatics Removal Act (1851), Indian Merchant Shipping Act (1859), Puri Lodging Houses Act (1871), Bengal Births and Deaths Registration Act (1873), Bombay Vaccination Act (1877), Calcutta Burial Boards Act (1811), first Indian Factories Act (1881), amended in 1891, 1911, 1922, Bengal Municipal Act (1884), Bombay Protection of Pilgrims Act (1887), Indian Railways Act (1890), Pilgrim Ships Act (1895), Indian Epidemic Diseases Act (1897), Indian Lepers Act (1898), and Indian Glanders and Farcy Act (1899). The passing of the first Local Self-Government Act in 1885 relegated the task of the promotion of sanitation to local bodies and village unions. The beginnings of political and social progress were thus laid here. Maternal and infantile mortality attracted the attention of voluntary workers, which resulted in the establishment of the Dufferin Association for supplying medical aid to women in India (1866),

the introduction of modern nursing (1869) and the starting of a Women's Medical College at Ludhiana (1894).

It is significant to note that while the recommendations of the Royal Sanitary Commission in England (1869–71) were implemented by continuous efforts to apply the knowledge gained from the discoveries of the medical science and by persistent State action to educate the population in matters concerning health and to develop the environmental and medical services, those of the Royal Sanitary Commission in India (1859) were relegated to the background as being inapplicable to the then Indian Community.

Forty years of the 20th century have seen enormous advances in medical knowledge and its application by the State in England and other Western countries, along with simultaneous social evolution and political progress. Each of the new discoveries in the various sciences opened up a new vista of possibilities for applying them to the well-being of man. The consolidation and co-ordination of the piecemeal measures of the previous century have helped to develop medicine as a social science and to restrict and defeat disease wherever it shows itself, to prolong human life wherever it exists and to build up and conserve health as such in the home, in the school, in the factory and in the field.

Let us glance, for a moment, at what was taking place in India during this period. In the sphere of medical research, Leishman and Donovan's discovery of the Kala-azar parasite (1903), the report of the Plague Commission (1904) and the discovery of Urea Stibamine by Brahmachari (1920) may be considered as important landmarks. Since the publication of the Report of the Plague Commission (1904), which advocated the reconstruction of the Sanitary Department on a wide imperial basis, and with the establishment of adequate laboratory accommodation for research, teaching, sera and vaccine production, the strengthening of it by the recruitment of scientific experts and the placing of the new service under the Government of India in respect of both the executive and scientific duties, the amount of medical and veterinary research carried out in about a dozen and half research institutions, in various spheres, has not been small but most of them have not been dictated by particular unsolved public health problems and even when their results have been made known there has been very little attempt to apply the scientific knowledge to the eradication of prevailing maladies and to the physical well-being of man and animals. The establishment of the Bacteriological department in 1906, most of whose workers belong to the Indian Medical Service, and of the Indian Research Fund Association in 1911 'with the object of ensuring a continuous supply of young workers of adequate calibre and of attacking such medical research problems as awaited solution' are to be considered as important steps in solving the urgent public health problems, although the manner

of their working is still defective and is capable of improvement. It has to be remembered in this connection that the Indian Research Fund Association is a much older body than the Medical Research Council in England (1920) which is doing excellent work.

In the sphere of medical education, a University grade and a lower (or school) grade of education have been prevalent since 1857, but the latter qualification is neither recognized by the British General Medical Council nor the Medical Council of India. The new University Regulations of 1906 tried to improve medical education and advanced studies, both of which need immediate reform to suit the requirements of the national health policy. The Indianization of some of the professorial chairs at medical colleges began in 1911 and the Indianization of the hospital staff began as late as 1923. The establishment of the Calcutta School of Tropical Medicine (1920) and of the All-India Institute of Hygiene and Public Health (1932) has made it possible for the post-graduate training of medical and public health personnel. The Medical Council of India (1933) aims at improving and standardizing medical education in India. Twelve Medical Colleges and 27 Medical Schools are now turning out about 700 graduates (including 100 women) and 1,500 licentiates per annum, the same number as England and Wales are turning out for 1/9th of the population of India. The requirements for the annual output of qualified doctors in India are far more than this. The total number of qualified doctors in India is 42,000 or one doctor per 10,000 population and that also very unevenly distributed, in contrast to England's one doctor to 800 persons.

During the latter half of the 19th century, the policy of the Government of India with regard to sanitation and sanitary staff was marked by vacillation but more activity was noticeable since the beginning of the 20th century. The Government of India formulated a forward sanitary policy in 1914 (Resolution dated 23rd May, 1914), when some useful principles of sanitary organization including research, sanitary surveys, urban sanitation (conservancy, water-supply, drainage) and town planning, rural sanitation, health education and the combating of epidemics, were laid down but they have hardly been properly implemented. The political and social awakening of the earlier years of the present century was followed by the Government of India Act of 1919 which accepted the principle of provincial autonomy. This led to the transfer of medical administration, including hospitals, dispensaries and asylums, and the provision for medical education, together with public health, sanitation and vital statistics, with certain reservations, to nominated ministers. Extra-provincial, inter-provincial and international matters, together with legislation for the control of epidemics were reserved by the Central Government.

By this time, informed public opinion began to demand more expenditure on public health. In spite of this demand, nothing more than a skeleton staff could be employed—being too inadequate for dealing with large populations and areas entrusted to them. For example, in Bengal, a Health Officer was put in charge of a district and a Sanitary Inspector with a Health Assistant and a Vaccinator was posted to each *thana* (1927). In most areas, the latter were expected to look after a population of 60,000 or more, living in 170 villages spread over an area of 80 square miles or more. In some areas, the same staff were expected to look after 120,000 people, living in some 800 villages covering 400 square miles.

Measures for the improvement of hygiene in industrial areas began to be taken since 1911—Indian Factories Act (1911), Indian Mines Act (1923), Workmen's Compensation Act (1923), Bombay Maternity Benefit Act (1929), Tea Districts Emigrant Labour Act (1932) and Employment of Children Act (1933). In spite of these, occupational hygiene is still a neglected subject in the Health Departments of the provinces. The Royal Commission on Labour (1931) recommended quite a number of public health reforms in labour areas and the co-operation of the League of Nations also stimulated the progress to some extent. Provincial Municipal Acts passed during this period, aimed at improving the sanitary condition of municipal areas but they have hardly developed any successful methodology of work and their administration is, in a large majority of cases, extremely defective. Legislation against food adulteration came in 1918-19. Attempts have been made to stimulate maternity and child welfare work since the beginning of the century by various non-official and official organizations by offering facilities for the training of medical and auxiliary personnel and for research. The maternal and infant mortality is still appalling.

Since the Indian Medical Service has until lately been responsible for looking after the curative and preventive aspects of public health in India, it will be noticed that many measures which were undertaken in India from time to time were but poor imitations of what was being done in England. Most of the public health expenditure has been made in urban areas, while rural health has been severely neglected. From a consideration of various factors, we are of the opinion that India stands now, from the public health point of view, where Great Britain stood 100 years ago, U.S.A. stood 75 years ago and where Russia stood before the Revolution.

Although 90% of India's population are still illiterate, various socio-economic and political factors helped them to demand public health reforms. The extension of franchise by the grant of Provincial Autonomy in 1935 has created a demand for social welfare in the modern sense and various Provincial Governments are seriously considering the planning of public

health and social welfare in their respective territories. The Government of Madras is the only Provincial Government which has passed a Consolidated Public Health Act (1939).

Any public health planning which is not based on sound scientific and proven principles is bound to fail. On the threshhold of further political and social progress in India, it may be useful to consider its various implications in their proper perspective. This is the only apology I have to offer for taking up the present theme for my Presidential Address.

The socio-economic position and its repercussions on Public Health

In considering the present public health position in India, one must remember that India is larger than Europe *minus* Russia; that she has 9 times the population of England and Wales and that her population has increased by over 250 millions within the last 90 years; that 90% of her population is rural in contrast to 20% in England, 47% in Canada and 50% in Japan; that 71% of the population are engaged in agriculture and that only 1% are employed in industries; that over 90% of the population is illiterate and that some of the social and religious customs are not conducive to good health. The urban population of British India amounts to 25 millions, out of a total of 350 millions.

The average per capita annual income in British India is £4-7*s*. or 1/15th of that in England and 1/18th of that in U.S.A. (Findlay Shirras). The monthly income per head, therefore, comes to about Rs.5, but the rural population earns less—Rs.39 per capita per annum or Rs.3-4 per month. From this, the average rural inhabitant has to provide himself with food, clothing and housing, pay the land revenue and very often interest on his loans for buying live-stock, seed, manure and other necessities. The quantity of arable land per person is too small and the quality of cattle too poor to provide him with the minimum requirements of a healthy life, while he cannot afford to improve the gradually impoverished soil. Underfeeding and unbalanced food necessarily reacts on the physique resulting in preventible sickness and lack of stamina. Dr. Aykroyd estimates that a minimum expenditure of Rs.5 to Rs.6 per capita per month is needed to provide an adult with minimum balanced nourishment. The percentage of taxation to national income in India is 10·1, in contrast to 8·7 in Switzerland, 9·5 in Canada, 13·3 in Australia and 25·6 in the United Kingdom.

The inhabitants of British India are stated to enjoy the briefest span of life, viz. 23 years, in contrast to Sweden's 62 years, Britain's 60 years, Germany's 58 years, Italy's 45 years and Japan's 45 years. The crude birth-rate per 1,000 in India is 34·5 (1937). The crude mortality rate per thousand in British

India (1937) is 22·4, as compared with 12·4 in England and Wales, 17·5 in Japan, 18·8 in Netherlands East Indies and 18·9 in Palestine. Of the 6·1 million annual deaths in British India (1937), fevers (in which are included malaria, enteric, kala-azar, tuberculosis, etc.) account for 58%, dysentery, diarrhoea and cholera together for 7·3%, respiratory diseases for 8%, infantile mortality for 24·8%, smallpox for 1% and plague for 0·5%. Infectious diseases like cholera, plague and smallpox, which have been almost entirely banished from the Western countries and Japan, still take as annual toll of 99,000, 28,000 and 55,000 lives respectively. The rate of decline in mortality from the diseases and from the vaguely defined category of fevers has been extremely slow, while in some cases, e.g. respiratory diseases, there has been a gradual increase. Child mortality rates at different age periods are from 3–5 times higher in India than in England. For the whole period 0–10 years, the death rate among children in India is 4 times as high as in England. Maternal mortality due to child-bearing exacts a toll of 4-5 times than in Western countries, 20% of the deaths being due to anaemia which accounts for a negligible fraction of deaths (0·05%) in England. 80–90% of these deaths are, therefore, preventible. It is estimated that about 30% or 3 million women are permanently or temporarily disabled in India as a result of pregnancy or labour every year. There are 150,000 lepers in India and over 2 million persons (40–70% of the population in some areas) are estimated to be infected with hookworm.

If the English death rate obtained in India to-day, there would have 2,766,049 fewer annual deaths (males—58, females—60), and the expectation of life would be 60, instead of the present 23 years. The sickness rate in England, entailing incapacity for work is 2% of the population. Even if we take the rate as 4% in India, the number of people constantly sick would be somewhere near 11 millions, chiefly through lack of medical protection. No work has yet been done in India to indicate the sickness rate in the general population. The sickness rate among the British troops in India is, however, 12 times, while that among the Indian troops is 10 times that of the death rate. If this basis of calculation is taken, the amount of sickness in the general population and the consequent economic loss due to loss of wages would be enormous.

Of the 6,500 curative institutions, 3,000 hospitals with 95,000 beds and 3,500 out-patient dispensaries are attending to 35 million new and old patients annually. 925 of these institutions are voluntary, the rest managed or aided by the State. Of 6,407 medical officers who are manning these institutions, 220 are I.M.S. Officers occupying the senior posts, involving an annual expenditure in pay and allowances, excluding pensions charges, of about Rs.60 lakhs; 41 are non-I.M.S. Europeans, 740 are missionaries; 105 are military assistant surgeons, 1,054 are Civil

assistant surgeons and the rest licentiates or sub-assistant surgeons. The number of doctors employed in public health duties is 1,206 or 1/5th of that employed on curative services, of which only 217 possess public health qualifications. A little over 50% of the 247 districts employ a Medical Officer of Health, the rest still remain unprovided with. This is also very unevenly distributed. Over 50% of the total budget (curative and preventive medicine) is consumed by the medical staff. The total number of registered doctors is 42,000. The number of students who qualified in 1936-37 were 965, of whom 100 were women. About 12,000 medical students are receiving instructions in the year. There are 3,697 nurses in India, of whom only 211 are employed in rural areas.

The average area served by each hospital or dispensary varies from 24 sq. miles (Delhi) to 1,327 sq. miles (Baluchistan) and the average population served by each of these institutions varies from 11,305 in Baluchistan to 81,087 in U.P. The per capita expenditure on medical relief varies from one anna in U.P. to Rs.1-2-5 pies in Delhi. The expenditure in urban areas is nearly three times that in rural areas.

No planning for the health uplift of a community is possible without a consideration of the topography, soil study and the raising of food, weather conditions, population (men and cattle), water-supply, drainage, industry, education and economic and cultural backgrounds of the community. A survey of these factors is necessary before any planning is undertaken. It will be found that, in most spheres, the deviation from physiological health is related to problems connected with housing, clothing, physical cleanliness, drinking-water supplies, disposal of sewage, household refuse and manure, and the contamination and poverty of foodstuffs. The backwardness of India in the proper evolution of public health must be accounted for either by the progress of science not being applied to the prevention of disease as it has been done in advanced countries or to a wrong application of the same. Before we proceed to suggest recommendations, it is necessary to ascertain the causes of the lag in India and how they can be remedied.

Causes of the lag between science and its applications in the improvement of Public Health in India and some suggestions for their removal

1. *Absence of any national health policy.*

As has been pointed out before, in England there has been a persistent endeavour to apply the knowledge gained from the discoveries of the medical sciences, in the course of the past 100 years, to the social, educational, economic and hygienic well-being of her citizens. The advent of the British rule in

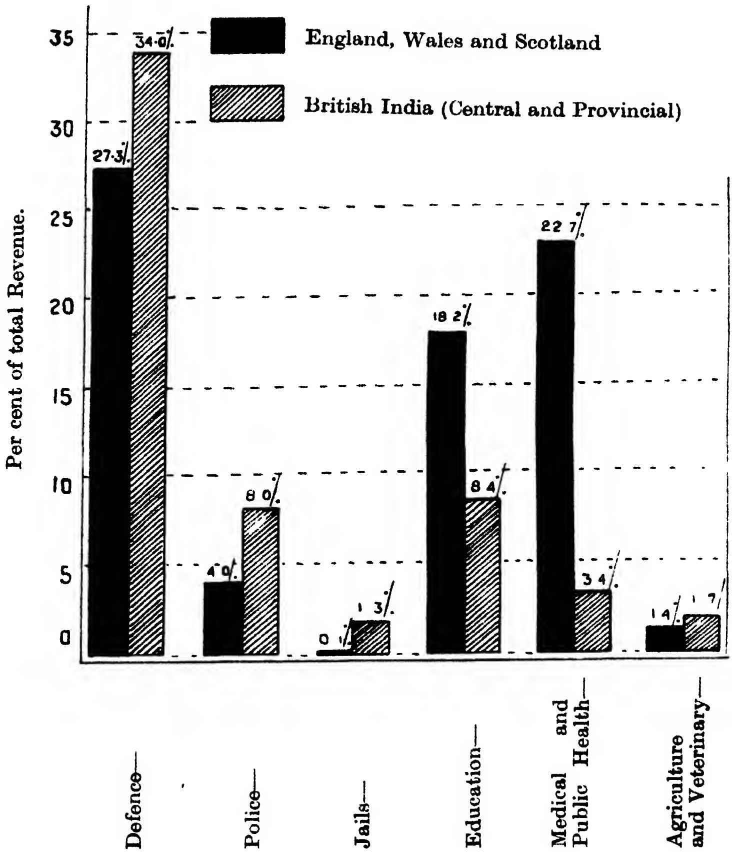
India coincided with the differentiation of science and its resultant industrialization in Europe. Instead of a continuous drive towards medical protection, health education and the provision of environmental services as in England, the administration in India showed a *laissez-faire* and vacillating policy. The medical and sanitary administration was bossed over by a Civil Service whose chief concern was to govern and to maintain law and order, without any perspective towards a co-ordinated development of the social services, such as education, agriculture, co-operation, public health, etc. Most of the personnel of these services appointed to look after the medical, public health and social services had no specialized training in the particular branches of the craft and hence there was little desire in them to utilize the scientific knowledge and discoveries of the times towards the betterment of the health and physical well-being of the population.

The medical personnel responsible for guiding the policy or for administration came and still comes from a highly paid service which has been primarily meant for the Army. Here also special technical knowledge and training were not considered to be the criteria for appointment in a particular post carrying a particular object, with the result that a man who began, for example, as a teacher of Anatomy was considered competent to be successively appointed a Divisional Surgeon, a Port Health Officer, a Radiologist, a Teacher of Medicine and so on. This principle is still being followed in the Imperial and Provincial Medical Services to the great detriment of the working machinery. The continuance of this system even in the 20th century when it is realized that medical progress cannot be possible without special training and competency accounts for a large measure of backwardness in medical and public health planning in India. This is the reason why Research and Medical and Public Health education 83 years after the establishment of the Universities in India are still hopelessly backward, as compared with other progressive countries. It is not my purpose here to underrate the excellent services rendered by the research workers and administrators of the previous generation who introduced Western medical science into this country and developed it, but there is no technical justification for its continuance in the present century, when there is a sufficient number of highly trained technical workers available in the country who can replace the superior services entirely without any loss of efficiency and run the organization at much less cost. In fact, the whole system of administration needs to be remodelled to suit the new conditions and requirements.

It has been pointed that there was hardly any public health policy until the reforms of 1919 and 1935. These reforms have no doubt stimulated a desire for progress but it is being hampered by the lack of a planned programme and policy, a hopelessly

inadequate amount being earmarked for medical relief and social services (*vide* histogram below), by the continuance of a top-heavy

Histogram showing some items of State Expenditure in percentages of revenue in British India (Central and Provincial) and England, Wales and Scotland.
1938-1939.



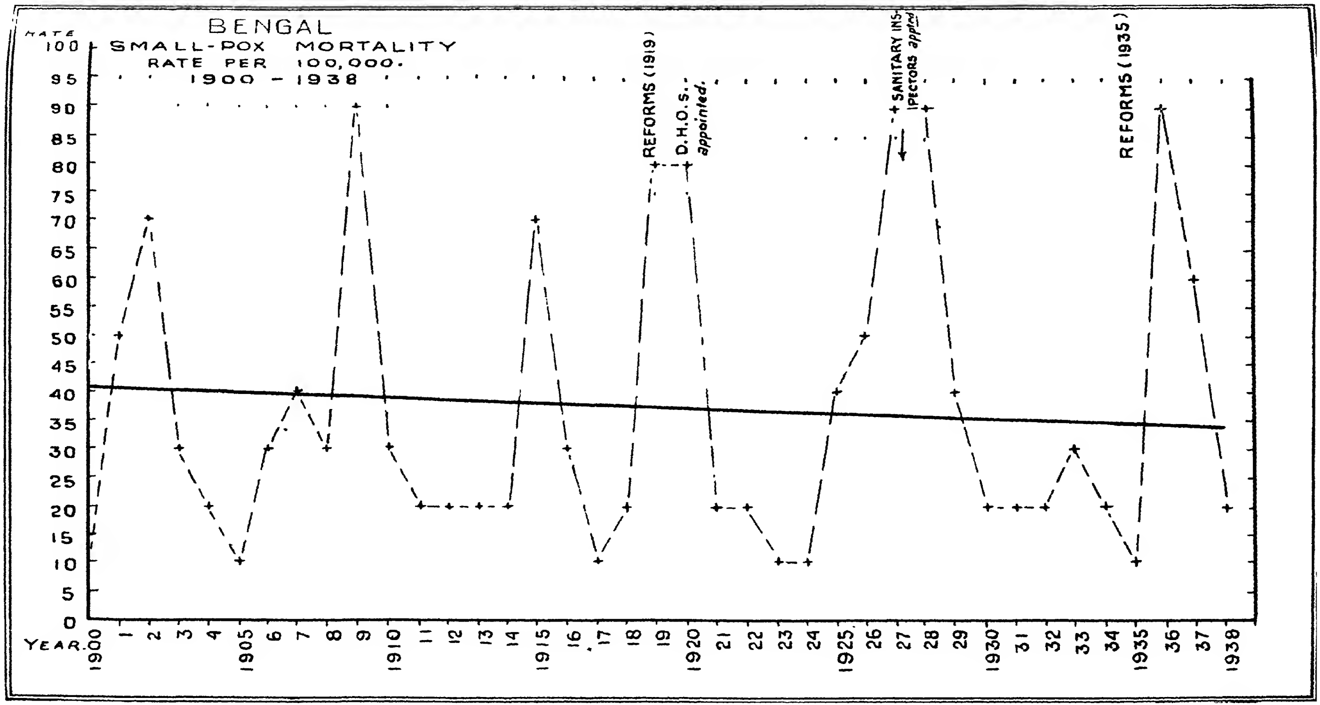
N.B.—No comparison has been made of figures relating to India with those of England and Wales in other fields of governmental activity, for the administrative set-up is so different in the two countries that they are not comparable.

administration without efficiently trained technical personnel and by the poverty of ideas in the administrators themselves. There is still considerable lack of co-ordination among the various

interdependent branches of administration which are concerned with a forward health policy and social progress of the population. Administrative procedures are often applied which are not based upon sound economic considerations and financial budgeting within the economic means of the population. The result has been that although some fragmentary public health measures have been undertaken in urban areas, the rural population has been hopelessly neglected, with the result that the villager in India to-day is no more benefited by modern science than his forefathers before the advent of the British rule.

2. *Violation of the essential principles of sound public health administration.*

India's lag in the utilization of science for the medical protection of her citizens through organized community effort is due chiefly to the absence of any national policy based upon defined principles. In most cases, all the six principles enunciated on pages (10) and (11) have been violated. The backwardness of India in health matters does not seem to be due so much to economic causes, ignorance or lack of medical facilities as to the lack of efficient public health and medical organization based upon the investigation of the most effective and economic methods of *applying* the results of scientific knowledge to the requirements of large units of population. It is true that Great Britain spends Rs.15 (1931) and U.S.A. spends Rs.30 (1932) per capita on medical and public health protection, but a comparatively much better result has been obtained in improving the situation in the Dutch East Indies with a per capita expenditure of 4·8 annas and in the Philippines with a per capita expenditure of 5·25 annas, in comparison with India's 3·5 annas (1931). For example, with a staff of 2,523 vaccinators (excluding Calcutta with 66 vaccinators) in Bengal, where Jennerian Vaccination was introduced as far back as 1803 (first in Asia) deaths from smallpox during the last ten years have numbered 166,000 (*vide* diagram below), whereas with a staff of only 150 vaccinators in Java, which has a comparable topography and population, the total deaths, mostly from imported cases, have been limited to 9 during the same period. It is further claimed in official reports in Bengal that during the ten years 1929–1938 over 8% of the population were *successfully* vaccinated every year at a cost of 1 anna 10 pies per head. The evidence depicted on the diagram can only point to one thing, viz. a wastage of time and funds, in spite of a large staff, chiefly due to defective methodology, supervision and control. Similarly, lack of co-ordination between the watertight departments of Irrigation, Railways and Roads and Public Health is responsible for a large percentage of India's 15 million annual deaths from man-made malaria. Take the case of nutrition again; when the health authorities detect


BENGAL
SMALL-POX MORTALITY
RATE PER 100,000.
1900 - 1938
RATE
YEAR.
REFORMS (1919)
D.H.O.S. appointed.
SANITARY INSPECTORS appt'd
REFORMS (1935)

malnutrition and deficiency diseases in a group of population, the remedy will lie with a co-ordination of efforts of the Communications, Agriculture, Animal Husbandry and Co-operative departments but none of them has yet carried science to the door of the ryot as in Java, Philippines or Japan. In the absence of such co-ordination, the ill-health continues and remains uncorrected. This is because India has not yet developed adequate knowledge of successful methodology and its community utilization and because public opinion is not properly educated, with the result that inefficient methodology has resulted in uneconomic and inefficient administration leading to wastage of funds which could better be applied to other fields. Before co-ordination can be of value, the fields to be co-ordinated must have the necessary technical content to apply known knowledge for a common purpose to groups of population.

Thus it seems that lack of a scientific outlook and an inadequate investigation by the administrative authorities in developing suitable methods of organization and the lack of a policy to include both urban and rural populations in a cognate whole as regards planning have been more responsible for her present backwardness than anything else. All scientific fields are governed by determinable laws, or else they are not scientific. It is of the utmost importance, therefore, that this country should make a general survey of the state of public health and of its health equipment, evolve a methodology of approach by carrying out sample experiments in different areas to understand the reciprocal co-ordination between the inter-related departments and its financial implications and, based on such findings, construct a coherent plan for a medico-social policy, fixing, year by year, the stage to be reached and securing the financial resources, in cash and/or kind, and trained personnel required for the purpose.

I shall cite a recent example from China (1934) when she was faced with developing methods within her economic resources. The help of the Peking Union Medical College was secured in developing the methodology of *School Health* on two economic standards. An 'A' service to demonstrate technical measures common in the West was provided entirely through cash purchase at a cost of 2·41 Chinese dollars (= Rs.2-6-6) per school child per annum. This, however, was impracticable of extension under Chinese economic conditions. Consequently, a 'B' service was developed at 64 cents (= 10as. 3p.) per school child per annum, which was economically practicable. The latter programme was developed on the basis that the essential measures should be undertaken by the voluntary effort of the teachers and pupils themselves and that cash purchase should be limited to provision of supplies and of technical supervision by the

medical officer and the school nurse. This applied to each of the three administrative sections, viz. Sanitation, Medical Service and Health Education. The practical essentials were water and sanitary toilets in Sanitation; routine appraisal measures of the individual pupil's health and prophylactic vaccinations under Medical Service, together with the correction of gross remediable defects; and the integration of healthful living and of health knowledge with actual living of the pupil in Health Education. It was shown that responsibility for the bulk of routine for the School Health Service could be placed upon the teachers and the pupils, provided two essentials were adhered to, viz. participative training of the teachers at a Demonstration Centre or a Science Institute and provision of adequate supervision of the established routine by the medical officer and the nurse. Thus it was possible to undertake the bulk of the essentials of a School Health Service through local voluntary effort, instead of cash purchase which was made available for technical supervision and medical supplies. This principle can easily be applied in India in many departments of public health where a complete cash purchase is not possible at the present moment, by securing the co-operation of the inter-related sections of social services.

If Great Britain can spend 18·2% of the revenue for education and 22·7% for medical protection, India should be ashamed to spend the insignificant percentage of 8·4% and 3·4% respectively of the revenue on these heads. Agriculture and Animal Husbandry may be less important in highly industrialized Great Britain, but it is of such vital importance to the health and life of the chiefly agricultural Indian population that a paltry expenditure of 1·7% of the revenue is scandalous. Rural hygiene, at least in its peripheral units, must be treated as a co-ordinated part of Rural Reconstruction, because rural health is very intimately bound up with the other economic and social factors pertaining to the improvement of the socio-economic status. Thus the departments of industries, irrigation, fisheries, co-operation and communications actively co-operate in other countries, with the public health programme in raising the stature of total health. It is a matter of great regret that these departments have hitherto failed to secure the necessary help and co-ordination in India. A national effort requires the pooling of all the available resources of the nation. The failure of such an effort has resulted in the neglect of proper drainage of the soil and the resultant creation of man-made malaria and in the development of communications without due regard to the requirements of marketing of agricultural produce and of the supply of medical aid to rural areas. It will thus be seen that, in national planning, any departmental planning must form an organic part of the total requirements.

In the maintenance of health, the State must provide for a social machinery to assure living standards adequate for the purpose. This refers to the improvement of economic status, nutrition, housing, physical fitness and recreation, co-ordinated with education and social assistance. Hardly any system of *social assistance* has been developed in India. Social assistance includes old age and invalidity pensions, compensation for physical injury or disease in the course of work, sickness benefit, unemployment benefit, etc. It must be remembered that in Great Britain, the National Health Insurance Scheme, which provides for medical assistance and other benefits in cash or kind to over 15,000,000 people between the ages of 16 and 70 years, is the largest health service outside the activities of the local bodies, which assume much more inclusive public health and social protection than in India. Prevention of disease includes impersonal services like food and drugs control, water-supplies, sewage disposal, etc., and the control of communicable diseases. The necessity for medical relief comes in where the efforts of the State to maintain the health and to prevent diseases have failed. As such, curative medicine should occupy a comparatively small place in the national health programme. This includes personal services, such as maternity and child welfare, school health and occupational hygiene and the institutions for the early diagnosis and preventive treatment of diseases—hospitals, convalescent homes, sanatoria and work colonies, dispensaries and peripheral health centres. Unless the Indian administration views at public health from this angle, the lag cannot be made up.

3. *Backwardness of, and lack of methodology in, education.*

Sir George Newman (1939) has said that 'National health—in every country in the world, everywhere, and all the time—depends upon first the knowledge of science or art of medicine discovered, tested, verified, proved and then upon its *social* application by the medical practitioner, by the State, and by the people of that State. *Without that knowledge, there is no knowing, without that application there is no going*'. The better application of this knowledge by the State and its wider usage by an educated and disciplined people is now recognized to be essential to ensure co-operation with any health scheme and to build up an efficient and healthy people. The lack of an aim and methodology in general education has resulted in wastage of effort and achievement of results in obtaining the necessary scientific outlook and in the intelligent participation and practice in social fields. Science is taught in a perfunctory manner in schools and the pupils seldom practise health and participate in public health activities. There is not a single official school nurse throughout India, whereas England employs 5,413. In the

same ratio, India would need 38,017. How can one expect to achieve results in India, if only 8·4% of the revenue, in comparison with Great Britain's 18·2% is spent for education and when teachers are not properly trained in the participation of public health work even for the school population, not to speak of the general population? A thorough overhaul of the general educational system has got to be fitted into the map of national planning.

4. *Defects in the training and supply of technical personnel.*

State Medicine has been defined as 'the rendering available for every member of the community, irrespective of any necessary relationship to the conditions of individual payment of all the potentialities of preventive and curative medicine'. The next in order of importance in health planning after developing the methodology is to train the appropriate categories of personnel in order to put into effect the methods for the whole population. The quality of medical care depends upon an intelligent interpretation of the correlation of scientific knowledge in its application to the needs of the individual. This can be accomplished only by trained and experienced personnel who realize the significance of that knowledge and have the discriminating judgment necessary for its proper use.

While continued endeavours have been made in Great Britain and other advanced countries since the early years of the present century to improve and adapt medical education to the needs of the changing socio-economic problems, the methodology of education in India has hardly kept pace with the changing environment and requirements.

The chief medical worker is the *physician*. He puts the teaching of medical science into practice and leads the people in their fight against disease and towards a healthier and more joyful life. The training of medical personnel, therefore, is an important matter in mobilizing them—for the type of service needed. Twenty-five years ago the medical curriculum in all civilized countries was directed to the study of morbidity; to-day the basic line is physiological. Medicine is now developing more and more into applied physiology. The new British medical curriculum (1938) has shifted the centre of gravity of medical education from the study of disease to the study of human health as the primary business of the student and has emphasized that a starting point for a medical course is not disease but health. The General Medical Council desired that '(1) throughout the whole period of study the education of the student should be directed by his teachers (*a*) to the importance of the measures by which *normal health* may be assessed and maintained, and (*b*) to the principles and practice of the *prevention of disease*; (2) instruction in normal reactions of the body to injury and infection, as an introduction to general pathology'. The Indian Medical

Council (1933) has also laid down 'that throughout the whole period of study the attention of the student should be directed by his teachers to the importance of the preventive aspects of medicine, and of measures for the assessment of normal health'. The ideas expressed above seem to be identical but their application is different, for none of the teaching medical institutions in India has so far put this principle into practice. In fact, the training imparted in this country seems to be exotic in character based on English methods and has frequently no bearing on the needs of the country or of a consistent public health policy. It is only a bad imitation of what is done in Europe.

Where medicine is so integral a part of the general life of the nation, the social sciences must be given a large place in the curriculum. A case of illness is to be discussed not only from the clinical or pathological point of view but in all its complexity including the social and economic factors involved. Thus sociology is coming more and more to the forefront in its manifold relationship to private and public medicine, to personal hygiene, to national health, to social and individual psychology, to the economic structure of the society and to public health administration. Unless the student realizes, during his period of training, that a knowledge of chemical, physical and biological phenomena of disease and of a grasp of the social and economic factors which influence the methods of dealing with sickness and prevention of disease are only tools which are being placed in his hands for service, he cannot be expected to be a useful doctor for the country. Health should mean more than the absence of disease; the spreading of disease should, therefore, become a social offence.

Sir George Newman's idea of a modern practitioner is that 'he should possess a preventive appreciation towards the wide field of prevention in general midwifery and surgery and that he should have a community consciousness and specific knowledge of the statutory obligations that he may possess'. If preventive medicine has to have a pervading influence in all parts of the curriculum, how is this to be imparted in the successive stages? From the very beginning the teaching of the clinical and non-clinical subjects may be brought closer together in their applied and public health aspects. It is not possible to introduce this unless the teachers themselves appreciate its importance and willingly co-operate in making it a success. So far as public health was concerned, the Peking Union Medical College in China tried an experiment (1934), which is worthy of consideration. As clinical clerkships are given to students in the hospitals to get an insight into the causation and pathology of diseases, in like manner public health clerkships were given to students for a couple of months at a Health Centre working in collaboration with the regional hospital. The students studied the cases in the field in all their clinical, epidemiological and social bearings

and control, and actually participated in the methods of application of public health procedures. This helped to remove the idea from the minds of the students that they had to deal with curative medicine alone in the hospital, as also after passing out. A close co-operation between the clinical and public health group of teachers and an arrangement for joint teaching were secured. It was found that when the students understood the epidemiological and social implications of disease or failure of health, both in urban and rural areas, they were more inclined to settle down in rural areas and thus began to render more useful service to the nation than in the past. This ('Permeation') experiment of public health clerkship might be tried in India not only to re-orientate medical teaching but also to encourage students to work in rural areas. Or, an experiment which was tried in Russia might be tried here, viz. of selecting students for admission into the medical schools and colleges from the areas where national health planning needed their services. Free-studentships and scholarships were offered to such students in Russia on condition that they practised in rural areas for three years. This is an alternative method by which the disproportion between the distribution of qualified doctors in urban and rural areas may be remedied. Once in three years, such doctors were required to undergo post-graduate instruction at the cost of the State, not only to stimulate the doctors thereby to contribute to advances in medical science but to assist them to place the new knowledge gathered at the disposal of the social, economic and communal needs of the society—nutrition, immunization, health education, physiological assessment, physical and mental welfare, etc.

The problem in India to-day is how to remedy the lag between scientific progress and its application to the benefit of the individual and the community, how to adapt our medical education to the needs of the changing socio-economic and political environment and how to train the necessary technical personnel for carrying out the national health programme and to supervise its various units. Let us try to estimate the number of doctors—institutional and public health—nurses, midwives, *dais*, dentists, pharmacists, sanitary inspectors, dressers, health assistants and publicity officers needed for an organization visualized as above.

We need three types of *doctors*—(1) practitioners for therapeutics (medicine and surgery) and general prophylactic workers, (2) public health physicians, and (3) specialists for the protection of mother and child. These may be considered as the officers in the army engaged in fighting disease but like every army the medical corps requires a large number of non-commissioned officers, such as nurses and technicians, without whom medicine will not fulfil its task. Health assistants, sanitary inspectors, midwives, laboratory technicians, dentists,

pharmacists' assistants, etc., may be included in the latter category. We need also an accessory type of personnel which consists of orderlies, hospital employees, ambulance drivers, etc. Lastly, the rôle of voluntary workers—men and women, boys and girls—affiliated to some social service organization should not be underestimated. The education and training of each of these categories of personnel have to be attended to in its theoretical and practical aspects.

There are 600,000 villages in India and, if we have to supply a qualified doctor, with public health qualifications, to a group of say 3 villages, we shall require 200,000 trained *physicians* to man the peripheral units of the rural medical relief *cum* public health organization. Besides these, we need better trained workers for the purpose of supervision or for supplying service which requires specialized knowledge and skill. Assuming that 10% of the total personnel would be engaged in supervision work, we need 20,000 supervisors. Besides these, specialized service may require another 10,000 highly skilled doctors. This means that if we are to reconstruct public health on a new basis, we should require at least 230,000 trained doctors of different categories. As a result of scientific medical training in India for the last 100 years the number of qualified practitioners is to-day only 42,000. If we have to go on at this rate it will take for us another 150 years to get the required number. Russia was faced after the revolution with the same problem. She was therefore compelled to quickly increase the number of medical students to get the required number of physicians. Between 1913 and 1933 the increase was 4 times. In 1913 the number of qualified doctors was 19,785, in 1924 it was 33,000 and it now exceeds 110,000. The training of other categories of personnel, which will run into several thousands, will also have to be thought of in terms of the developing needs of the situation in a given area.

Medical education will have, therefore, to be thoroughly reorganized and adapted to the new requirements. Social science must be given an adequate importance in the curriculum. It will not suffice for the student to get his training in the hospital wards alone but it should be extended to community fields, in order to give him an idea of the applicability of medical knowledge towards the maintenance of health and prevention of disease in the community. The university should not only arrange to train the necessary personnel but also help in evolving practical methods of solving the various problems and to extend those methods to the community. The appointment of a Chair of Medical Sociology and one of History of Medicine seems to be an urgent initial step.

As in medical relief so in public health, we should have field demonstration centres, urban and rural, in connection with

teaching. These will supply a student with a proper outlook about his responsibilities to the community, without which he is likely to be a misfit. It has already been said that the failure to establish scientific methodology in determining tools for community welfare is one of the chief factors responsible for the present social lag throughout the world. Successful methodology for community utilization of knowledge within economic practicability will also have to be taken up by the universities for investigation. So long as we cannot secure the required volume of personnel, the lag between this and the community utilization of knowledge can be considerably removed if we have at our disposal a successfully tried methodology for the application of public health reform and medical protection. For example, in spite of an insufficiency of trained personnel in Java, small-pox and cholera have been practically wiped out at less cost per capita and less staff than in India.

It will be pertinent in this connection to think of what is going to happen to the indigenous systems of medicine which have been prevalent in India since the ancient and mediaeval days. I cannot do better than quote, in this connection, the following extract from the Convocation Address of Sir Nilratan Sircar, delivered before the Andhra University on the 7th October, 1939: 'With the establishment of provincial autonomy in the provinces, efforts are being made to give official recognition to the Ayurvedic, Unani and Homeopathic systems of medicine. The basic sciences of chemistry, physics, biology, physiology, pharmacology, pathology and bacteriology are the same all over the world. The present tendency to register practitioners of various so-called systems of medicine, lacking systematic scientific training of any sort, is a move in the wrong direction. We do not call a barrister or an advocate now practising in India according to communal denominations. Science is progressive and must be the same throughout the world. The criterion of the right of a doctor to medical practice, or to the privilege of registration, must depend on the basic knowledge he possesses of the fundamental sciences of chemistry, physics, anatomy, physiology, pharmacology, pathology and of medicine, surgery, midwifery, and other cognate subjects. No system of medicine, Ayurvedic, Unani or any other, can get on without the help of modern basic sciences. There should be no spirit of communalism or opportunism of false economy concerning matters of life and death of millions of ignorant and helpless villagers whom we have failed to educate or elevate. The question of prevention of epidemic diseases cannot be successfully solved, unless scientific methods of proved efficiency are adopted. How can we apply all the different systems of medicine towards the end? The proper move should be to have only one medical science which has been worked out by the scientists all over the world, incorporating into it whatever good there may be in the

indigenous medical sciences of the country. If this is done there will be only one medical register in the country which should facilitate the control of medical relief and sanitation for the entire population. It is for this reason that I am compelled to discourage the teaching of the so-called medical systems, without the help of the basic sciences. If India is to achieve her place among the first rank nations of the world, she must advance with the help of modern sciences and she must discourage retrograde measures of the sort that are being encouraged in some of the provinces, without forethought and imagination.'

5. *Research and public health progress.*

Medical and Veterinary Research in India has been shabbily treated and badly organized. Researches have been carried out on many diseases in India but very few of them have been undertaken to solve specific health problems and, even when the results of such investigations have been made known, there has been little attempt to apply them into practice. For example, the Plague Commission of 1895 carried out excellent investigations into the epidemiology of plague; still 31 years after the publication of the report plague caused 28,169 deaths in one year (1937) and the Public Health Commissioner for India opined that unless cheap designs for rat-proof houses could be designed, as in Java, for rural areas, where 92% of the deaths occurred, the prevention of plague could not be effected. How is it that in one country the lag between knowledge and its application (Java) has been overcome and not in the other (India)? Likewise the Public Health Commissioner notes (1937), with regard to cholera, that 'If every Indian village were provided with a protected water-supply and were to practise a sanitary method for the disposal of refuse and night-soil there would undoubtedly follow a marked and permanent reduction in the incidence of bowel diseases, such as cholera, dysentery, diarrhoea and typhoid, whilst guinea-worm infection, which causes a large amount of suffering and incapacitation, would also be suppressed'. The installation of tube-wells has been suggested as a remedy. Further, it is noted that only 13% of towns with a population below 30,000, 56% having a population between 30–50,000 and 78% having a population of over 50,000 have a piped water-supply. The number of villages with protected water-supply is stated to be negligible. These diseases caused nearly 500,000 deaths in the year 1937. If only a fraction of the economic loss consequent on death and invalidity from these diseases could be spent in adopting methods which were developed by field research, this unnecessary wastage of human life could be prevented. But the lag could not be removed here, as elsewhere, owing to inadequate investigation and the adoption of a bold public health policy. A similar lag is noticeable in

the conservation of animal health in the interests of human health. It is needless to emphasize the importance of field enquiries in a country which is chiefly agricultural and where every variety of soil, climate, race, diet and habits is prevalent. The universities and their affiliated medical institutions have neglected to encourage applied medical research and have failed to keep a living contact with the needs of the country. A thorough reorganization of the educational system, particularly in its scientific aspects, is urgently called for.

Researches should be centralized in order to ensure co-ordination and avoid overlapping. The provinces may take up local problems, while the centre may take up problems of an all-India character for investigation. This necessitates careful planning and co-ordination of various schemes of research in all branches of science, whether pure or applied. Pure scientific research is as essential as that specifically devoted to the attainment of any medical, public health or industrial object. The detailed planning of research must be in the hands of those with the necessary specialized knowledge and they must be able to act without suspicion of political or racial influence. The formation of a National Research Council for India is overdue. With a view to harnessing science in the service of man, it is necessary to explore ways and means for extending the existing machinery of scientific education in the country, from the school to the university stage, develop applied scientific training and research, and, finally, to see that such research is undertaken with a definite end in view and not outside the ambit of planning for public health. The most useful investigation at the present moment should be directed to the extension of medical knowledge for actual utilization by the villager. The universities in India have hitherto failed to fulfil their research function, because of the service organization and of the multifarious obligations of the workers in affiliated medical institutions.

Hardly any investigations have been carried out in India on *occupational hygiene*. Industrial medical research can be divided into two categories:—(1) physiological research concerned with the study of the effect of environment and of occupation of the individual and (2) the organized application of science to the population in providing standards of medical protection for the maintenance of health and cure of disease and thereby increasing the output and welfare of labour. It is necessary for this purpose to organize fundamental 'pure' research at central or university laboratories and 'applied' research in the industry itself, thus establishing a channel of communication between fundamental science and its application. Industrial medical research is successful in proportion to its co-ordination with the national planned organization of science. This visualizes a horizontal all-India scientific planning organization, constituted as part of national economy from which various

special vertical functions would be derived, of which one would be industrial scientific research with a specific division for Medical, in so far as it relates to problems arising from the human factors of production.

Apart from research, the economic implications of health protection of the worker needs the development of a well-planned system of *social insurance*. The system of social insurance differs, as regards its thoroughness of protection and organization in different countries; it is more thorough in Soviet Russia than in the Western European countries. Before India wishes to adopt any one system, it is necessary to study the methodology of its applications in the field. This will save unnecessary complications and wastage of efforts in future.

Having devoted the first eleven years of my career to the bacteriology, pathology and clinical investigations of a number of human diseases, I realized the close relationships of social science to research when I took up tuberculosis as my object of study fourteen years ago. I got the first insight into the problem by a study of the epidemiology and pathology of the disease. Although some bacteriological investigations were taken up, they were undertaken with a view to solve related but unsolved problems. The problem as to how tuberculosis reacts to industrialization in an agricultural country is now engaging our attention. Since tuberculosis is a social disease, the investigation of the home conditions and environment of the cases cannot be left out of account in studying the disease. Thus I have been dragged from the laboratory to the ailing man, his home and environment, his place of work and the hazards to which he is exposed there, and to his habits, customs and movements. The study and prevention of such a disease need planning and team work for the elucidation of problems and extensive education and suitable administrative action by the State and Local authorities for prevention. The application of the results of research ought to be the duty of the people and the State.

6. *The supply of drugs and instruments.*

In spite of the fact that India abounds in all kinds of medicinal plants (Col. Chopra estimates the number to be 2,000) and in spite of the fact that many potent drugs had been used in India since the pre-Christian era, it is a matter of great regret and shame that no attention was paid to a rational and scientific investigation of the drug resources of India until lately by the Calcutta School of Tropical Medicine and still later by a few other centres. Although it is true that a few useful drugs have already been found, out of nearly 200 medicinal plants investigated by Col. Chopra and his collaborators, it must not be forgotten that it has taken 20 years for them to tackle 1/10th of the drug resources of the plant kingdom.

It is estimated that approximately 90% of the population of India have to take recourse to the use of indigenous drugs, partly because drugs manufactured by the Western system are more costly and partly because no arrangement exists for the medicinal treatment of the rural population.

Col. Chopra is credited with the statement that nearly three-fourths of the medicinal plants mentioned in the British and other pharmacopoeias grow in India in a state of nature and that others can be easily grown. No attempts have, however, been made to systematically cultivate and study Indian medicinal plants for supplying the population with cheap drugs for the treatment of so many preventible diseases in India. For example, take the question of the supply of quinine. In spite of the fact that, in the absence of more permanent methods of eradication of malaria, the administration of quinine is considered to be the only feasible and economical anti-malarial measure in treating about 100–200 millions of the infected population, India produces barely 1/10th of her requirements of this drug and imports the bulk of it from Java at a higher price than the cost of production in India. Recent investigations have shown that 38,000 acres of suitable land are available in India for Cinchona cultivation which could yield seven times the quinine required for India. This is another illustration of how things are done in India. It is said that the cost of free distribution of quinine is very much higher than the price of the drug itself, the cost of the drug per individual being only four annas and its free distribution costing from twelve annas to a rupee.

The *laissez-faire* policy of the Government has resulted in the export of raw materials from India and to the import of finished products into this country, resulting in an economic drain. It would be interesting to know that during the year 1928-29, drugs exported from India amounted to Rs.42 lakhs, while the figure for imports was Rs.200 lakhs. Tea dusts of over 400 million pounds are annually exported at a nominal price, while it comes back to us as alkaloid caffeine valued at Rs.6,57,600. It is understood that caffeine could be easily manufactured in India at competitive prices, provided the railway freight of tea dusts is reduced. It is reported that the lag here had been the unwillingness of the Tea Associations of India in permitting the manufacture of caffeine from waste tea in India. If the State had a policy to foster the development of manufacture of indigenous drugs, they could have easily overridden these objections of an organization with vested interests. The same may be said of many drugs like nux vomica, belladonna, castor oil, etc.

The total consumption of drugs in India prepared by Western methods in 1938-39 was Rs.2,20,53,230, of which India produced roughly not more than Rs.75 lakhs worth of drugs, and to produce this quantity of drugs raw materials to the value of at

least Rs.10 lakhs had to be imported. India has to depend on foreign countries on the supply of basic chemicals for the manufacture of drugs, particularly alkaloids, organic and inorganic acids, coal and wood distillation products and various solvents used in the manufacture of synthetic drugs. Unless the coal distillation industry is properly organized, India will have to depend on foreign countries for the supply of most of the synthetic drugs, at a higher expenditure, which are needed for medical relief.

Thus, while the output of drugs manufactured by the Western method is small compared with the requirements, the vast proportion of the people, chiefly in rural areas, are compelled to use indigenous drugs prepared by Vaids and Hakims, 0·1% of whom possess the necessary training and scientific background. The responsibility for this widespread use of unscientific medicine lies in the lack of a planned programme to reach scientific medicine and tested drugs to the door of the humblest citizen. Attention should, therefore, be directed to the following immediate requirements which have been accentuated by the recent military blockades: (1) the manufacture of chemicals including solvents, (2) the production of synthetic drugs of known value, (3) an expansion of the investigation of Indian medicinal plants with a view to replace foreign drugs, including the study of Ayurvedic and Unani drugs and their standardization in known Western terms. This will be one of the means to supply cheap medicines to the population suited to the climatic conditions of the country, and (4) the cultivation of medicinal plants in suitable areas with a view to secure a standard yield of the active principles of drugs. The above investigations no doubt require extensive research by chemists and pharmacologists in close co-operation with the manufacturers. Naturally, no single institution is in a position to undertake this huge task. The Chemistry departments of various universities, the Pharmacology departments of the different medical colleges and various official and unofficial research institutes may be requested to take up the problem, according to a planned and co-ordinated programme, directed by a Central Advisory Board, consisting of the different categories of scientific workers, chemists, pharmacologists, botanists and industrialists. The State should come forward and take the initiative to set up the organization and to supply the necessary funds. As soon as the researches reach a certain stage, an attempt should be made to compile an Indian Pharmacopoeia, for without the standards laid down in such a publication the manufacture of the different medicinal preparations and their standardization will be rendered difficult and slow. It is firmly believed by many pharmacologists, botanists and chemists that India can be made self-supporting as regards her drug requirements and that the treatment of many diseases could thus be provided within the means of the Indian masses,

whose paying capacity is unfortunately very poor, provided there is a national planning in this regard and provided the necessary co-operation and co-ordination are forthcoming between various Government institutions, universities and non-official workers engaged in similar or allied investigations.

The remarks which apply to drug supply also applies to the supply of instruments. In spite of 150 years of contact with Europe, India has still to import most of her technical instruments and apparatus needed for the diagnosis, treatment and investigation of diseases. Compare this with Soviet Russia. In 1912, she imported 59% of the total value of drugs used; by 1934 the imports were only 3% of the total value; by 1940 she must be self-sufficient in this regard. By the middle of 1935, there were 2,500 X-ray apparatus of Soviet manufacture already in use; quartz lamps and diathermy apparatus of home production were also coming to the market; the output of satisfactory surgical needles and syringes was reaching a high figure; and by the close of the same year, a supply of some 850 dentists' chairs was proceeding from shops established a few months ago.

7. *Financial handicaps to progress.*

Modern public health, which is an integral part of the social services like education, agriculture, animal husbandry, co-operation and industries, has to be paid for. It has already been pointed out that the social services in India are starved at the expense of a top-heavy administration and a high expenditure on defence and police. The salaries in the superior services in India are often 3-4 times higher than those paid in France or Japan. The actual amount spent on defence and police in India is higher than what appears superficially to the casual observer. For example, the percentage of revenue shown as being spent on defence does not include the cost of Frontier defences and the heavy loss on strategic railways is stated to be shown under other heads. If these are included, the proportionate cost on defence will be much higher than what has been in Britain before the present war, in spite of the fact that India hardly possesses a Navy and an Air Force. The top-heavy administration here as elsewhere absorbs a major part of the budget. Similarly, 75% of the Union Board rates, at least in Bengal, is made to pay for the *chaukidars*, or peripheral police agents, leaving very little for putting into operation social welfare services in the villages.

The percentage of revenue spent on education in Britain is over twice, while that on preventive and curative medicine is nearly 7 times of what is spent in India. The following comparative tables of expenditure on certain social welfare services in England and Wales, India and Bengal will be found to be illuminating.

Comparative per capita expenditure on certain services in India and Bengal.

	India as a whole (Central and Provincial only) 1937-38.	Bengal.		
		Provincial 1939-40.	Municipal 1937-38.	District Board 1937-38.
	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
General Administration	0 7 6	0 5 0	....	....
Administration of Justice	0 3 0	0 3 6	....	....
Jails	0 1 3	0 1 0	....	....
Police	0 6 6	0 8 0	....	0 1 6
Education	0 7 6	0 4 6	0 4 0	0 1 6
Representation in Indian States	0 0 6	....	....	....
Audit	0 0 6	....	....	....
Tribal Areas (Defence from raids) ..	0 1 0	....	....	....
External Affairs ..	0 0 3	....	....	....
Medical	0 2 6	0 1 7	0 3 0	0 0 9
Public Health ..	0 1 4	0 1 4	0 2 5	0 0 9
Agriculture ..	0 1 4	0 0 6	....	....
Veterinary	0 0 3	0 0 1	....	....
Industries	0 0 6	....	....	....
	2 1 11	1 9 6	0 9 5	0 4 6
		0 9 5		
		0 4 6		
		2 7 5		

Comparative Expenditure on Social Services in England and Wales and Bengal.

Bengal—Provincial, Municipal and District Board (1937-38) as compared to England and Wales (1935).

	Expenditure on Social Services.		Annual per capita.		Percentage of total expenditure on Social Services.		Percentage of Social Services expenditure to total Provincial, Municipal and District Board expenditure (Rs.14,49,59,409).	
	England and Wales.	Bengal.	England and Wales.	Bengal.	England and Wales.	Bengal.	England and Wales.	Bengal.
	000 Rs.	000 Rs.	Rs.	Annas.	Per cent.	Per cent.	Per cent.	Per cent.
Education	1,41,74,40	1,71,60	35·5	6	26·25	48	10·70	11·0
Medical .	31,76,53	76,78	6·5	2½	6·00	23	2·40	5·0
Public Health		58,94		1½		17		4·5
TOTAL ..	1,73,50,93	3,07,32	42·0	10	32·25	88	13·10	20·5

Provincial Expenditure on certain Social Welfare Services in Bengal.

Bengal—Provincial, Municipal and District Board (1937-38).

	Expenditure on Social Services.	Annual per capita.	Percentage of total expenditure on Social Services.	Percentage of Social Service expenditure to total Provincial, Municipal and District Board expenditure (Rs.14,49,59,409).
	000 Rs.	Annas.	Per cent.	Per cent.
Education ..	1,71,60	6	48	11·0
Medical ..	76,78	$2\frac{1}{2}$	23	5·0
Public Health ..	58,94	$1\frac{1}{2}$	17	4·5
Agriculture ..	11,53	$\frac{1}{4}$	3	1·0
Veterinary ..	7,22	$\frac{1}{6}$	1	0·5
Co-operation ..	11,61	$\frac{1}{4}$	3	1·0
Industries ..	16,05	$\frac{1}{2}$	5	1·0
TOTAL ..	3,53,73	$11\frac{1}{6}$	100	24·0

It will be futile to plan a co-ordinated scheme of public health, as has been visualized here, with such an insignificant allocation to the social services. More money has, therefore, to be made available for them. There are *three ways* of finding out more money for the cash purchase of public health: (i) to make more allocations out of the existing budgets to the social welfare services, or (ii) to increase the income per capita and thereby the taxable capacity of the people, or (iii) to make use of both these methods. The second of these methods requires a thorough national planning in economic uplift and will probably require many years before a satisfactory result is achieved. Owing to the urgency of national health reform in India, however, it seems feasible to suggest some sources from where money may be made available. The first and foremost is the reduction in the scale of salaries in the superior services. A 'Rolls Royce administration' cannot be maintained in a 'bullock-cart' country, and so long as the population remains underfed, uneducated and without the minimum requirements for a healthy living, a racial discrimination in the services is no longer tenable. In many departments of social welfare, the salaries of the superior staff swallows up 60–80% of the

total departmental budget. This is a financially unsound policy and should be abolished. To take the medical services as an example: out of 364 Indian Medical Service Officers, who are meant for military duty, as many as 220 are employed in the Civil departments in the provinces and the Centre. Their salaries and allowances, excluding the charges payable in pensions, amounts to about Rs.60 lakhs a year, of which Rs.16 lakhs are spent in England comprising leave salaries, deputation pay, sterling overseas allowance, etc. In Bengal, the non-voted expenditure on Medical and Public Health departments amounts to Rs.8,73,833, of which Rs.2,19,749 constitute expenditure in England, out of a total budget of Rs.96,56,296 (1938-39). The principle of employing the members of a service, liable for transfer to military duty, without any regard for technical competency and continuance of tenure, interferes with technical progress and throttles the extension of public health measures to large groups of low-income population. While not belittling the contributions of this service in the past, there is no technical justification for continuing the system in the development, distribution and application of scientific knowledge in a poor country like India any longer. If continued further, it will only act as clogs to the wheel of progress. The Military Assistant Surgeons, of whom there are 105 in Civil employ, are in a similar category. Sheer national necessity compels us to propose drastic reductions in the salaries of the superior services in order to make more money available for the social services. As an example, it may be mentioned that the transfer of the I.M.S. Officers from Bengal will supply a Public Health Nurse to each *Thana* Unit, totalling 575. Such a transfer will not hamper the efficiency of the administration, in the least, if the existing services and talents now available in the country are properly trained and mobilized. The same holds good for other superior services. Besides this, there is much anomalous difference in the scale of salaries of the various services which are expected to do the same or a better type of job. For example, medical officers in charge of hospitals who do not possess post-graduate qualifications in public health or any other subject are given the same salary as District Health Officers with D.P.H. qualifications and are allowed to practise at the same time. Moreover, the District Health Officers have a non-pensionable service, whereas the State Medical Officers attached to hospitals have a pensionable service. This is not only an injustice done to the Health officers but also to the general medical profession who have to face an unfair competition. Moreover, if the honorary services of competent members of the general medical profession are secured for the hospital services, much of the over-head cash expenditure in curative medicine can be reduced. It will thus be seen that nothing but a thorough reorganization of the services and a

sound national financial planning will meet the needs of supplying the minimum requirements for a healthy living for the whole population. If India could manage to spend Rs.20 lakhs a day now to meet the military obligations of the present war and if lakhs of rupees could be collected in the provinces for War Purposes, it would not have been impossible to mobilize the necessary finance for a national planning in peace-time had there been a desire and a policy in the administration to pursue a forward programme.

8. *Lack of institutional planning.*

Hitherto, hospitals have developed in most countries in a haphazard fashion according to the dictates of charity or exigencies of situation regarding the occurrence of diseases. Modern medicine has made diagnosis and therapy of diseases not only a highly specialized procedure in many cases but a costly method beyond the reach of many individuals in the community. In order to offer such diagnosis and treatment, free or at a nominal cost, to those who need it, it is necessary to plan the institutions on a regional basis according to the incidence of particular diseases in an area. If the findings of the Bhopal survey are taken as a basis, only 4% of sick people in this country require specialized treatment in highly equipped hospitals with specially trained personnel. These findings may not apply to all areas and, therefore, each area needs to be surveyed. When this is done it will be found that costly institutions with highly specialized staff will not be needed in such large numbers as now, if the distribution of hospitals and dispensaries is planned in such a way that minor ailments are cared for at the peripheral dispensaries, ordinary hospitals take care of the intermediate categories of cases and the difficult cases are taken to the highly specialized base hospitals. What happens now is that the city hospitals, like those in Calcutta, which possess highly efficient and expensive staff and equipment, deal with all sorts of cases, involving not only in wastage of time of the specially trained staff but of money as well.

To reach medical aid speedily to those who need it and to transport them to larger institutions where the necessary equipment and skill are available, a suitable planning in the development of communications is absolutely essential. It is a matter of regret that communications have not been developed in India to serve the needs of sick population.

Further, the tendency to construct stately buildings for hospitals in this country, which sinks most of the funds in brick and mortar, leaving very little for equipment and efficient running and service, is to be deplored. Cheaply constructed

hospitals which can last for twenty years would tide over the initial stages of economic planning and pave the way for better buildings when money can be made available, but for this appropriate research should be undertaken. We hardly find any indications for this in India.

As first steps to remove the lag, every province should have a committee on hospital standardization and planning, on which the medical associations should be represented. It will be the business of such a committee to survey the needs and suggest suitable standardized plans for different categories of institutions. If this is done, it will be found to be not only less costly but the community needs will be more efficiently met *through proper zoning.*

9. *Lack of co-ordination between the inter-related administrative departments.*

The Department of Public Health or Social Affairs is intimately related to the Department of Rural Reconstruction, which again is related to the Departments of Education, Agriculture and Animal Husbandry, Industries, Communications and Irrigation. Owing to a lack of proper co-ordination between them, many excellent public health schemes never fructify, to the great detriment of the well-being of the population for whom they exist. The functions of the Finance Department are said to sit on files for as long as possible and to prevent expenditure wherever possible. In order to bring about this co-ordination, England had to establish a Ministry of Reconstruction in 1919 and China had to establish a Ministry of Co-ordination in 1929. In the State, the health programme is only one part of the great national programme. Therefore, all Government agencies are allies and all should work towards the same end. The State has only one purpose—to promote the welfare of all its citizens without distinction, to raise their material and cultural standards and to liberate them from the bonds of poverty, ignorance and disease. The physician or health worker in such a State is a specialist who knows about disease and who works towards the fulfilment of the general plan side by side with the other civil servants.

The establishment of provincial ministries of health and a federal ministry of health in India is absolutely essential as a first step towards securing this co-operation. It is desirable that in the provinces, the necessary co-operation between health (including housing, nutrition, physical fitness, maternal and child welfare, school medical services, hospitals and supervision of the medical profession), public relief and social welfare institutions should be co-ordinated or united in a single Ministry of

Public Health or Social Affairs, which keeps in close touch with the institutes of Hygiene and co-operates, as much as required, with the medical faculties. The Ministry should secure the opinions of an Advisory Board, preferably consisting of non-service people with special knowledge of health questions, on all important aspects of public health planning. The division and technical value of the work should be so directed as to secure the maximum of efficiency with the minimum of expenditure, which will again be guided by the principle of co-ordination, unity of action and adaptation to local conditions.

The question of a federal ministry of health in India has been mooted since 1920, but it has not yet been solved. The formation of the Central Advisory Board of Health in 1937 was a move for interprovincial co-ordination, but it is only an advisory body without any power to enforce decisions where attempts at co-operation fail. This necessarily entails some retransferance of power from what has been given to the provinces by the 1935 Act. Without an All-India Public Health Act much progress is not possible. Only one of the provinces (Madras) has passed a Public Health Act (1939), but unless the other provinces possess it, very little co-ordinated and standardized progress will be achieved. In other words, the federal and provincial governments should sit together to frame a scheme of national planning in public health and social welfare according to modern conception and within the economic competency of the people.

It will be too diffuse an attempt to visualize the financial implications of such a scheme on an all-India basis, but we shall try to present the underlying principles of a scheme for a province, taking Bengal as an example, because the population of Bengal approximates that of England and Wales and of Java, two countries with two different orientations.

The Planning of Public Health in a Province, with special reference to Bengal

The League of Nations Report on Medico-Social Policy in rural areas (1939) lays down that 'Medico-social policy in country districts should begin by the organization of arrangements for *medical care*. This is the normal course of historical development for the protection of health, and it is but natural that the first step should be that of meeting the most immediate and keenly-felt need. The sick suffer, and to relieve them is a humanitarian duty; it is also the means of paving the way for preventive medicine, which, from the standpoint of public health, is more important than curative medicine, though as yet less appreciated by the public'. From what has already been said, it is evident

that the State must be responsible for all medical work, viz. curative (or clinical) as well as preventive (or social) medicine, for the training and provision of all cadres of personnel, and for all types of establishments and supplies. It is understood that the service should be provided without any charge to the people, and yet the total cost must be such as the people are able to bear indirectly through taxation. In India, for a long time to come, financial stringency may limit the extension of these services, but, provided a methodology is devised whereby the payment for the purchase of health can be made in cash and in kind, so long as the economic condition of the country does not improve to a sufficiently high level, a substantial degree of progress can be achieved. In some European countries, the public relief authorities pay selected general practitioners for attendance on the poor and, through the extension of sickness insurance and other forms of collective medical assistance, the sick are given access to the whole armoury of preventive and curative services. This has been found to prove less expensive in the long run for the responsible agencies. From what has been said before, it will be needless to elaborate on the individual items, but, in order that an efficient organization is built up, the State medical service must be operated 'with the discipline expected of a military machine and with the economic management associated with an industrial enterprise'. The success and efficiency of any group action depends upon organization and supervision. The traditional functions of the doctor, nurse, midwife, pharmacist, etc., and of traditional hospitals, clinics and health bureaus must be scrutinized and, if they do not fit adequately into the new scheme, they must be altered. If necessary, new types should be evolved to take the place of the old.

The *training and supply of personnel* is a very important matter. With regard to the vehicle and content of medical education, certain changes from traditional forms will be needed to suit the requirements of the organization dictated by modern State Medicine. Practical training of all classes of personnel would be undertaken in both the urban and the rural units, so that the finished products are able to take their place in the service without undergoing further special training, which will thus result in a saving of time and funds. Post-graduate and Refresher Courses are expected to keep the knowledge and efficiency of the personnel at the proper level.

In order to attend to the socio-economic factor, the public health activities must be linked with those of rural reconstruction, they being mutually interdependent for success in either sphere. 'Preventive and curative medicine cannot be separated on any sound principle, and in any scheme of medical services must be

brought together in close co-ordination.' The preventive measures may be divided into the following categories: (1) the development of a social machinery to assure living standards adequate for the maintenance of health, (2) health education, (3) sanitation of environment, (4) epidemiological control of communicable diseases, and (5) organization of early diagnosis and preventive treatment of disease.

The improvement of sanitation of villages is possible only when the sanitation of every house is improved. To appreciate the magnitude of this statement, we may quote some findings of a health survey in one of the units (Closepet) subsidized by the Rockefeller Foundation in India.

Twenty-five per cent of the families in this unit had an income under Rs.5 per month, 30% had a monthly income of Rs.5-10, 25% between 10 to 15 rupees p.m., 10% between Rs.15 to 20 p.m. and the rest above Rs.20 p.m. 30% of the families had only one room, the rest more than one room. 1·5% of the houses were provided with latrines, the rest had no latrines. 70% of the houses had no windows and 25% of the houses were unfit for habitation. 50% of the houses were without drains and in 50% of the houses the cattle were kept in living quarters. In 40% of the houses the kitchen refuse was stored in the backyard and in 15% it was thrown into the streets. In 40% of the houses, the sullage water was led into the backyard and in 50% it was led into the street. There was very little provision for safe drinking water. In 30% of the houses the manure was stored in the backyard and in the rest it was sent out to the fields.

Naturally, in such a population as this the improvement of environmental conditions is beyond the competency of a health organization, unless there is co-ordination with other social services through a department of Rural Reconstruction, which comes forward to plan and co-ordinate the Social Services, of which Health is one. Even the Department of Rural Reconstruction will find it impossible to obtain the desired results unless the villagers themselves become health conscious, through persistent health propaganda and practice and come forward to participate in the health activities of Social Welfare Leagues established and managed by them. The participation of village headmen, school teachers, medical practitioners and officers of the respective State departments will help a long way towards achieving the object.

The results obtained in the Closepet Centre was very encouraging as regards the improvement of school hygiene, control of epidemics, vaccination, vital statistics and reduction of maternal and infantile mortality. It was shown that infant mortality among cases conducted by the Centre was 76 per

1,000 livebirths, as compared to 157 in cases conducted by the local *dais* and that the maternal mortality in cases conducted by the Centre staff was 1·8 per 1,000 births, as compared to 8·1 in cases conducted by the local *dais*. It has already been shown in India that public health can be profitably purchased *in the army and jails*. Among the British troops, the death rate has been reduced from 13·03 in 1900 to 2·15 in 1937 and among the Indian troops from 10·87 to 1·77 respectively. The death rate in Indian jails has been reduced from 32·80 in 1900 to 10·25 in 1937. The sickness rate has also been greatly diminished. These evidences should infuse us with a hope for the future, provided a suitable planning is made based on experimented and successful methods.

It is to be noted that these Rockefeller-subsidized Demonstration Health Centres do not deal with curative medicine; still the expenditure per capita comes to annas 12. Such an expenditure is beyond the competence of provincial Governments at the present moment. Each of the five peripheral units at the Closepet Centre (= 50,000 population) catering to the needs of 10,000 people, employ one Sanitary Inspector, one Vaccinator, one Public Health Nurse, 2 Midwives and 2 Peons, supervised by a Central Staff of one Health Officer, one Assistant Health Officer, besides 2 clerks.

As regards the implications of curative medicine we have no data to go by, except a statistical study spread over six years in Bhopal State. It was found that 83% of the total ailments were amenable to simple treatment, if given in time; that 13% needed hospital care and that 4% required specialized treatment. This means that in a population yielding 10,000 patients 830 cases would need attention for minor ailments at a peripheral dispensary, 130 cases would have to be taken to a hospital centre for care and that arrangements would have to be made for the remaining 40 cases for specialized treatment at a more highly organized centre. Besides these, beds would have to be reserved, at suitable centres, for the isolation of infective cases, incurable cases, convalescent cases, maternity and gynaecological cases and sick children. Tuberculosis, leprosy and mental diseases would need separate arrangements. The system of travelling dispensaries and subsidized rural practitioners has proved a failure in India; hence arrangements would have to be made for permanent units according to the varying needs of the population.

Organization of Provincial Social Welfare Services

The functions and divisions of a Provincial health organization are illustrated in the following scheme:—

Organization of Provincial Social Welfare Services.

Ministry of Social Affairs.

Director of Public Health or Social Affairs.

Department of Rural Reconstruction.

Co-ordination. ↔ Dept. of Education.

Co-ordination. ↔ Dept. of Agriculture, Co-operation and Animal Husbandry.

Co-ordination. ↔ Dept. of Industries.

Co-ordination. ↔ Dept. of Communications and Irrigation.

Public Health Administration.

1. Finance and Pay.
2. Establishments.
3. Personnel (recruitment, transfer and promotion).
4. Supplies; production of drugs and appliances.
5. Survey and Research.
6. Education and Propaganda.
7. Vital Statistics and Records.
8. Legislation.
9. Supervision of the medical profession.

Service: Urban and Rural.

1. Co-ordination with Social Welfare.
2. Social assistance.
3. Environmental sanitation.
4. Communicable diseases control—general and special. Laboratory services.
5. Maternal and child health control.
6. School health control.
7. Nutrition and housing.
8. Physical fitness.
9. Occupational health control.
10. Food and drugs control.
11. Curative Services:
    Hospital.
    Dispensary.
    Domiciliary.

TRAINING.

1. Training of→ Doctors, curative and Preventive.
   —University grade.
   —School grade.
2. Training of assistants.
   (*a*) Sanitary Inspectors.→
   Village Health Assistants.
   Dentists
   Laboratory technicians.
   Pharmacists.
   Dressers.
   Orderlies.
   Publicity Officers.
   (*b*) Nurses: →
   Public Health and institutional.
   Midwives.
   Dais.
   (*c*) Post-graduate → and Refresher Courses.

Experimental and Community Field Training Centres.

Direction, Supervision and Control.

Provincial Centre.

District Stations.

Sub-divisional Stations.

Thana Stations.

Village Units.

Homes | Environmental | Schools | Places of occupation.

It will be seen that a separate Ministry of Social Affairs, which includes both preventive and curative medicine with the associated Social Services, has been proposed and that the present dichotomy of preventive and curative medicine has been proposed to be abolished, bringing about centralized control under an officer, who may be called the Director of Public Health or Social Affairs. As curative medicine occupies a small portion of modern preventive medicine, it has been proposed to abolish the posts of Inspector-Generals and Surgeon-Generals and to put an officer properly trained in modern public health administration in charge of all the sections. The posts of District Civil Surgeons may be abolished in view of the fact that the District Medical Officer of Health is to function as the Head of the District preventive and curative services.

The District organization, as applicable to Bengal, is shown in the following diagram:—

SCHEME FOR

DISTRICT HEALTH ORGANIZATION IN BENGAL

Population	= 50 millions.
No. of Districts	= 26.
Population of a District	= 1·2 millions.
No. of Sub-divisions	= 72.
Population of a Sub-division	= 500,000 to 700,000.
No. of Thanas	= 600.
Population of a Thana	= 50,000 to 80,000.
No. of Union Boards	= 5,084.
Population of a Union Board	= 5,000 to 10,000.
No. of villages	= 100,000.
Population of a Village	= 250 to 500.

Provincial Headquarters.

District Headquarters.
(= 3–5 Sub-divisions)
(Base)

Sub-divisional Centre. Sub-divisional Centre.

Sub-divisional Centre.
= 8-9 Thanas.
(Tertiary Centre.)

Thana
(Secondary Centre.)
(= 4-5 Peripheral Units.)

P.U. P.U. P.U. P.U.

Peripheral Units
of 2 Union Boards.
(Primary Centre).

(P.U. = Peripheral Unit.)

In the initial stages, the *peripheral village unit* or *Primary Centre* is proposed to include two Union Boards. Each Primary Centre will be equipped for services of both curative and preventive medicine. It will have a clinic, a dispensary and 5 beds, 3 of which will be meant for emergency aid and two for abnormal midwifery. The staff will consist of a doctor, an Instructor midwife, a compounder and two Health Assistants. The Primary Centre will ordinarily deal with the correction of minor defects and ailments. The beginnings of a domiciliary service may also be attempted here. School health may be looked after, with the voluntary assistance of school teachers. School teachers may also be utilized in vaccination and other types of work, e.g. health education which they can undertake with short training. As regards maternity service, it will be the business of the Instructor midwife to mobilize the indigenous *dais* to train them and to secure their co-operation. In a population of 20,000, 400 confinements are expected to occur annually, of which 10% may be abnormal. One-third of this may be tackled by the trained Instructor midwife. The remaining two-thirds will have to be sent to the next higher Centre (Thana), if expert medical aid is not available locally. The necessary supervision and co-ordination can be exercised from the Secondary or thana unit. The peripheral health centres should be under a single management and should help to co-ordinate all the relevant activities in the territorial zone. They may extend their activities by local branch agencies or by mobile units.

Four to five Primary Centres will constitute a *Secondary or Thana Centre*. The Thana Centre will have a 50-bed hospital, containing 10 beds each for medical, surgical, maternity, pediatrics, and infectious cases. Less than 50 beds in a hospital will increase the overhead cost. There will be a male doctor and a female doctor in charge of the hospital and for the supervision of the Primary Centres. The hospital, apart from attending to such cases as it can manage, will serve as a sorting and diagnostic centre, sending the more difficult and appropriate cases to institutions possessing more elaborate equipment and staff at subdivisional or district centres and to special institutions like tuberculosis hospitals and sanatoria, psychiatric institutions and convalescent homes. If funds permit, a Visiting Public Health Nurse may be stationed here to control the work of Instructor midwives and to train village *dais*. The staff and organization may be augmented as the work increases and as more funds become available.

The Thana units will be connected to the more highly organized *Sub-divisional Centres*. Each Sub-divisional Centre is to have a 100-bed hospital, with 20 beds for each of the sections provided for at the Thana Centre. There will be a male and a female Resident Medical Officer for the hospital and a male or

female officer for the clinic and one or two Public Health Nurses. The public health side of the work will be in charge of a Sub-divisional or Assistant Health Officer who will exercise both executive and supervisory functions. There will be a diagnostic laboratory attached to the hospital. If competent doctors are available at the Sub-divisional town who are prepared to work as Honorary Physicians or Surgeons to the hospital or clinic, their services should be thankfully accepted provided they undergo a short course of training at the Experimental Training Centre, which will be attached to the Sub-divisional Centre. This training centre will be responsible for training midwives, health assistants, compounders and nurses, will develop the methodology of work applicable to the area, and will assess the cost and results of the technique employed. It will also help in stimulating the local authorities and the population to extend the public health activities. This method has been found useful in several European countries and in U.S.A., China, Ceylon and some parts of India (Rockefeller Units). There will be some auxilliary personnel attached to the Sub-divisional Units, such as Sanitary Inspectors and Health Assistants to control epidemics, if and when they occur, and Publicity Assistants to aid in health education. A School Health Officer may be appointed, if funds are available. If not, the voluntary services of teachers may be requisitioned, while exercising supervision and training by technical staff.

The Secondary Health Centres must be equipped in such a way that they are able to supplement the work of the Primary Centres on the technical side and that patients may be moved from one institution to the other as needed. The division of work between these centres will depend mainly on the means of communication available and on whether the population is scattered or concentrated.

The Sub-divisional Centres will be connected with the more highly developed *District Centre.* The District Centre will exercise all the functions of the subsidiary centres but in a more specialized way. They will also supervise the work of the whole District. The District headquarters will have a 250-bed hospital, with 50 beds for each of the different categories of services. Special beds for tuberculosis may be added to this. This hospital will be fitted with all necessary modern equipment and will be staffed by competent officers. Ten to twelve Resident doctors will be needed to run the institution under a whole-time Superintendent. The voluntary services of specialist practitioners in the District headquarters should be utilized as far as possible. The laboratory attached to this hospital will undertake diagnostic, water analysis and food control work. There will be one urban and one rural Demonstration *cum* Training Centre attached to this hospital. This will offer training facilities for Sanitary Inspectors, institutional and public health nurses and

post-graduate and refresher courses for the higher personnel employed in the District. The whole administration will be under a Medical Officer of Health, who will be assisted by specialist officers for the special functions of the District organization. It will be seen that the administrative unit suggested corresponds to the political unit, which fairly corresponds to the distribution and agglomeration of population, marketing and transport arrangements. The suggested scheme is capable of expansion without essentially changing its structure. The first 5 years in this planning may be occupied in organizing curative and preventive services to units of 20,000 people. When more experience is gathered and mistakes are avoided, the Unit may be duplicated or even triplicated.

The District Health Administration constitutes a link between the provincial and local administrations. It should extend to social preventive medicine (health visitors, maternity and child welfare, anti-tuberculosis work, etc.), public health (housing, water supply, sewerage, etc.) and hospitals, carrying out a uniform programme everywhere and aiming at developing the various institutions into a balanced whole. The present isolationist policy of hospitals and dispensaries should be abandoned. In a planned policy, one hospital may deal with say acute diseases, another with chronic diseases, a third with convalescent cases and so on.

The proper training of the medical personnel needed for the proposed framework is a difficult matter. Experience has shown that a minimum annual expenditure of Rs.5 lakhs is needed to run an efficient medical college or school. In the initial stages, it may not be possible to equip such an institution for every district. Efforts should, however, be made to have such an institution in every Division, which usually consists of 5 districts. The supply of medical licentiates to medical graduates in India to-day is in the proportion of 2 : 1. Before the school system of training is abolished, arrangements should be made to provide facilities for the training of the medical and public health personnel, needed for the new organization, at the teaching institutions and field training centres. It would be worth considering whether, after the first 2 years' basic training in the medical colleges, curative and public health physicians' training should bifurcate in order to save time and expense in the initial stages of execution of the scheme, when a sufficient number of qualified personnel may not be available. The position in Bengal is different, as there are already 1,000 doctors employed in rural dispensaries and 2,000 are practising in rural areas. Out of over 11,000 registered doctors in Bengal, only 3,000 are in rural areas.

The Provincial headquarters will provide facilities for the training of the superior personnel and specialized services and will make arrangements for research activities for solving

problems offered by the District and subsidiary units. The training programme should be drawn up with a view to fit it into the eventual whole scheme and the methods devised should first be tried experimentally at selected centres before their general application is advised, in order to avoid wastage of efforts and funds in future. The Provincial health organization should have the help of an Advisory Board, consisting of experts in each line, preferably non-officials, who will study problems and offer such advice as they think fit.

The inspection and control of health work under the local bodies should be left to the Director of Health or Social Affairs. Dual control of work under the Government, local bodies and voluntary organizations of the present time has often resulted in the creation of many administrative difficulties, frequent dislocation of work and serious indiscipline in the ranks and resentment on the part of local bodies. This policy has already been adopted in Madras, Punjab and U.P. and should, therefore, be followed in the rest of India.

The idea is that the curative and preventive services should form a co-ordinated whole, ensuring every rural family a minimum of attention, especially in cases of confinement, infectious disease or accident and in those requiring urgent medical aid. The final goal should, however, be to provide for the whole community the services of doctor, midwife, nurse, specialists and dentists, in addition to laboratory analyses and hospital treatment. The aim should be to prepare a stage-wise and co-ordinated programme 'covering at one and the same time both central and local administrations, both environment of the family and the individual, both preventive and curative action'.

Financial implications of the Provincial scheme (Bengal)

Any scheme in which the overhead charges exceed 30% of the total earmarked budget is financially unsound. Hence, the salaries of the services should be adjusted according to the income per head and taxable capacity of the people.

The close participation of the Rural Reconstruction Department, which aims at co-ordinated uplift of the population by all the branches of the administration, will not only speed up the public health progress but will save a considerable expenditure for social-*cum*-public health progress. Any planning in public health is closely related to the general national planning.

It is understood that the construction of the quarters for the health personnel and of the hospitals and clinics will be undertaken by the local population. It will serve the purposes of national planning, if cheap materials which may last for 20 years or so are utilized in the construction of houses and institutions. Russia was compelled to adopt this for economic reasons in the initial stages of planning. If the methods of

national planning succeed, it may be possible to replace the temporary structures by more permanent materials at a later stage. It is also understood that the local population will voluntarily and actively participate in improving personal hygiene and environmental sanitation.

The recurring annual expenditure of a peripheral or Primary Centre will be Rs.3,000 p.a., that for a Thana Unit Rs.10,000 p.a., that for a Sub-divisional Unit Rs.50,000 p.a. and that for a District Centre Rs.100,000 p.a. This gives us an expenditure of about Rs.2 crores for the rural public health organization in all the districts. To this should be added the cost of central or basal supervision and training centres—Rs.100,000 p.a. Rs.20 lakhs p.a. will be needed for 4 Medical Colleges in the four Divisions of the Province for training the medical and public health personnel. Besides these, a certain amount of capital expenditure (about Rs.5 lakhs) will be needed for equipping the institutions with instruments, appliances and drugs. The development of the Social Assistance machinery is an urgent necessity in the furtherance of public health. The expenditure on this head cannot be visualized at this moment.

Let us see how the expenses can be met. The urban population in Bengal is only 1/16th of the rural population. Yet the per capita expenditure on curative and prevention services in municipal areas is Rs.2-1-9, in comparison with only 4 annas and 4 pies in rural areas. In order to divert more money to rural areas, the Government contribution to municipal areas will have to be starved for some years. Excluding municipal areas, the Government contributes at present (1940-41) Rs.87,83,000, the District Boards Rs.35,38,000 and the Union Boards Rs.14,21,403 or a total of Rs.1,37,42,403 to preventive and curative services. Thus there is a deficit of a like amount in financing the suggested scheme. This can be made available from various sources. One of them is more Government allocation to social welfare services. Out of a total per capita expenditure of Rs.2-7-5 in Bengal, Police expenditure absorbs 8as. and General Administration and Administration of Justice together absorb 8 annas 6 pies per capita or a total of more than a rupee per head, while only 4 annas 6 pies per capita is given for education and 3 annas per capita for preventive and curative health services. Compare this with the per capita expenditure of Rs.35-9-0 for education and Rs.6-9-0 for medical relief and public health in England and Wales. The other inter-related social services in provincial budgets are similarly starved at the expense of a top-heavy and maladjusted administrative machinery.

The scheme which we have ventured to suggest can be made practicable if the cost now being paid by the Government, District Boards and Union Boards is doubled. The present per capita expenditure from these sources is 2 annas 9 pies, 1 anna 1 pie and 6 pies respectively or a total of 4 annas 4 pies.

By doubling the figures, the respective contributions will be 5 annas 6 pies, 2 annas 2 pies and 1 anna or a total of 8 annas 8 pies. The municipal expenditures are left out of account. This is the minimum from where a start can be made. Provided the willing co-operation of the population is secured, enough contributions in kind will be available for the expansion of the scheme.

Bengal Government's recent scheme.

The defects in a skeleton scheme of supplying one Sanitary Inspector, one Health Assistant and one Medicine Carrier to each Thana Unit, numbering 575, introduced in 1927 in Bengal have already been referred to. Recently the Director of Public Health in Bengal has formulated a rural hygiene programme by combining curative and preventive medicine by a Rural Medical Officer, two Health Assistants, a part-time *dai* and a part-time cleaner to 2,500 rural medical units, each comprising two union boards. These are proposed to be linked, for purposes of supervision and control, to Secondary Centres in the sub-divisions under an Assistant Medical Officer of Health, assisted by 2–4 Sanitary Inspectors and office staff. These Secondary Centres are proposed to be linked to the District headquarters under a District Medical Officer of Health. The financial implications of the present organization and the proposed scheme are given below:—

Contributions from.	Per capita expenditure.								
	Present organization.			Proposed scheme.			Total.		
	Rs.	A.	P.	Rs.	A.	P.	Rs.	A.	P.
Government .	0	2	9	0	0	9½	0	3	6½
District Boards ..	0	1	1	0	0	1	0	1	2
Union Boards ..	0	0	6	0	0	8½	0	1	2½
Municipalities ..	2	1	9	0	0	½	2	1	9½

The additional expenditure needed in this scheme are Rs.22,77,000 from the Government, Rs.2,27,000 from the District Boards, Rs.21,10,000 from the Union Boards and Rs.66,000 from the Municipalities.

It will be seen that, although it marks an advance in the concept of rural health organization in this scheme, the co-ordination and control of the existing curative medical organizations (existing and future hospitals and dispensaries) have been left where it is in the present dichotomous structure, viz. under the Surgeon-General and his subordinates, which goes entirely against the idea of unitary control recommended in all modern public health schemes. This scheme may, however, very well

function as the starting point, provided the principles of public health administration enunciated by us are followed. The scheme seems to be capable of expansion when the necessary personnel is trained, adequate supervision is secured, the methodology developed and funds made available.

Summary and 'First Steps'

1. A historical review of the evolution of public health in India and in other countries, particularly England and Wales, has been given. The result of this evolution in Eur-American countries has been that to-day community medical protection has become a field of social activity. The major functions of social life have been mentioned and the fields of social welfare explained.

2. Some principles of sound public health administration have been laid down.

3. The causes of the lag between science and its application in the improvement of public health in India have been indicated and suggestions for their removal have been offered. Emphasis has been laid on the need for a scientific approach, hitherto lacking in India, to modern public health through adherence to the essential principles of public health administration.

4. The essentials for the planning of public health in a province, with special reference to Bengal, are discussed and the working principles defined.

The 'First Steps' in a province, will be for the department of Rural Reconstruction, which should be a co-ordinating department, in every province to set up a Planning Committee, with sub-committees on Social Welfare and other technical fields of rural reconstruction. The 'terms of reference' should be to define clearly the objective, to advise on the best way of developing and demonstrating the methodology of work proposed, to determine how best to apply the same in the wider fields around, to determine the method of training the required personnel and of proper supervision, control and maintenance of their level of efficiency, and to suggest the best means to secure the co-operation and co-ordination of the inter-related departments.

If our suggestions are looked at from a constructive viewpoint, the Rural Reconstruction departments in the various provinces will be expected to move in the matter and to determine what steps are practicable in applying the various principles for efficient and adequate community medical protection in their own territories. I have heard people to say that unless we get complete political and fiscal freedom no progress is possible. I do not subscribe to this view, although I admit that freedom will speed up the progress in every direction. I firmly believe that if we have in us the 'will to live', we are capable of purchasing public health by payments in kind so long as adequate cash is

not available, but for this a national desire to live which is noticeable in other nations, should be present in everybody and voluntary participation must be forthcoming.

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SECTION OF AGRICULTURE

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Presidential Address

(Delivered on Jan. 3, 1941)

PLANT BREEDING AND GENETICAL WORK IN INDIA

CONTENTS.

I. Introduction.

The President of this section last year made a departure from the usual custom of confining the address to a branch of the subject he was most familiar with, and gave instead an address on a general review of the progress of agriculture. I shall, however, revert to the usual practice. Last year's address had a large portion of it devoted to the value and care of seed. It is probably in the fitness of things that my address deals with the problem of search for, and production of seed with inherent superior characteristics. I shall make a general survey of the plant breeding and genetical work in India and in doing so, refer largely to two crops, rice and cotton, with which I am most familiar.

Scientific breeding with crop plants has become a powerful and indispensable tool for making agriculture more efficient and more flexible in meeting new demands and supplying the needs of men for food and raw material. "In the realm of living things with which agriculture deals, the work of the breeder is comparable to the work of the inventor in the realm of inanimate things with which industry deals, and his work pays in the same way that invention pays by replacing continuously the old by the new or making possible what was not possible before". The growing of improved types involves no additional expense to the cultivator and the work of breeding improved types has formed an important plank in the activities of the agricultural departments right from the very beginning.

Plant breeding in its strict sense means the production of better crops, the ultimate test of superiority, with exceptions, being greater yield per unit area and hence greater return to the grower. In the case of industrial crops like cotton, besides yield, the question of quality also comes into consideration in deciding the return per acre and hence breeding for quality does form part of the breeder's objective. At the present time breeding for quality in cotton has become an urgent necessity in several tracts since the bulk of the cotton produced in India is of short staple, the outside market for which has considerably dwindled. Breeding for quality in food crops, cereals, is still not of much importance in our country as the term 'quality' is incapable of a precise definition and usually has no bearing on the nutritive value. To mention only one example, the quality in rice, as is commonly understood, depends upon the size and colour of the grain and upon the extent of polishing it has received. Quality from the nutritional point of view is, however, quite different and if practical effect is to be given to the findings of research work on this problem, (Ramiah *et al.*, 1939) we shall have to radically change our ideas about quality in this most important food crop of the country.

Even in industrial crops, for various reasons beyond the control of the grower, yield under Indian conditions still forms the predominant factor. Let me try to illustrate this with a small example in cotton. The local indigenous cotton grown in Central India is of a poor quality, the lint capable of spinning only 10–12 counts. There is, however, the Upland cotton, which is definitely superior to the indigenous in quality and commands a better price in the local market, but does not yield quite so well as the indigenous as a rain-fed crop. Examination of extensive data on spinning quality and market price for cotton (Panse, 1940*c*) has brought out the fact that the premium obtained for the superior quality of Upland cotton can compensate only a ten per cent. reduction in yield while field trials have shown that the reduction in yield by substituting indigenous cotton with Upland is much greater than this figure, and hence it is not profitable to grow Upland cotton in Central India on rain-fed land.

II. A Survey of Plant Breeding Results.

i. *Results of plant breeding.*

Scientific plant breeding which is not more than thirty years old in India, has been carried on along the traditional lines of selection, introduction and hybridization. In fact, the methods followed are the same that have been followed in the West and the principles involved, which are fundamental, are applicable to all plants in general. It may be worth while at this stage to take stock of the practical results that have emerged so far from this plant breeding work. The only measure of the success of this work is the total area occupied by the improved types in various parts of the country. Taking India as a whole, the total area under the four important crops and the area devoted to the improved types evolved by the Departments of Agriculture are given below for the year 1937-38.

Crop.	Total area (acres) under the crop, (*thousands*).	Area (acres) devoted to improved strains, (*thousands*).	Percentage.
Rice	72,277	3,759	5·2
Wheat	35,618	6,930	19·5
Cotton	25,583	5,672	22·2
Sugarcane ..	3,818	2,855	74·8

The area under the improved types of sugarcane is very striking because the superiority of these types over the local, which these have replaced, has been phenomenal. In fact, the

benefit that the country has gained by the results of plant breeding in this one crop, which can be valued in several crores of rupees, has become a classical example of plant breeding achievement, the credit for which goes, in a large measure, to one of our own members and an ex-President of the Congress, Rao Bahadur T. S. Venkataraman. It may be mentioned in this connection that the protection given to this crop has been an important contributory cause for the rapid spread of improved types of sugarcane. That the area under improved types in other crops is not so striking is due to various causes. For one thing, except in the case of cotton and sugarcane, it is so difficult to estimate with any degree of accuracy the area under the improved types, the figures given above, being only rough approximations. Though the percentage area under improved varieties of rice is not considerable taking the country as a whole, it is certainly very much higher in individual provinces like Madras and Bengal where plant breeding has been carried on in this crop for a considerably longer period than in other provinces.

ii. *Spread of improved types.*

Botanists working in the departments of agriculture might produce better types of crops by breeding, but owing to the peculiar conditions in which Indian Agriculture is carried on, small and scattered holdings, the special tenancy systems, financial instability of the grower, the necessity to sell the produce with the seed as in cotton, etc., it is almost impossible for every individual cultivator to multiply his own seed from the improved types and an organization is necessary to make such seed available to the cultivator. The extent of such organization varies in different provinces and States in India. While some provinces like the Punjab spend several lakhs of rupees every year in the multiplication and distribution of seed of improved varieties, there is hardly any expenditure under this item in some other provinces. It must be mentioned here that the amount involved is not a gross expenditure to Government, but only represents a sum invested and later recouped by the sale of the seed. Owing to sudden fluctuations in the market prices, particularly in industrial crops, it is possible there may be a small loss incurred, in certain seasons, but, considering the practical benefit realized, the loss, even if there should be any, can be safely ignored. In the case of cotton, the Indian Central Cotton Committee finances several seed distribution schemes in different provinces and States. Because of the limited funds at the disposal of the Imperial Council of Agricultural Research, they were mainly concerned with financing research schemes and now that the resources of this body are likely to be augmented, it is up to them to see whether they should

not initiate and partly finance seed distribution schemes also in cases where such help should prove necessary and useful.

We cannot unfortunately compare ourselves with countries in the West on this question. There, the multiplication of improved types of crops and making them available to the cultivator is carried out by professional seedsmen as a business. In fact, in some countries like Denmark and Sweden, the seedsmen themselves do the work of breeding superior types. Most of the advanced countries have also Seed Acts in force prohibiting growers from using seed which is not pure and certified. The only non-official organization that might take up this work is special Co-operative Societies and although a certain amount of such work is being done in India, the output forms an infinitesimal proportion of the total requirements.

Any increase in yield which does not come up to ten per cent is rather difficult to be appreciated by the cultivators and in fact, this is the minimum figure aimed at by most plant breeders under ordinary methods of cultivation. In several cases, the improvement claimed by the breeder as a result of extensive trials, is much above this figure. It is generally the experience of plant breeders that improved types respond very much better than the unselected types to more intensive methods of cultivation.

Of the four crops mentioned above, dropping out sugarcane where the area under improved types is very high and has hence markedly increased the output in the country, the question may be raised whether on account of growing improved types in other crops, the output of the country has been perceptibly increased. Persons who do not believe that much benefit has occurred from plant breeding work often compare the standard yields of crops per acre as published in the crop statistics of India with those of other countries to support their case. In the case of rice crop, for instance, the average acre yield in India, which is 825 lbs. in 1937-38, is about one-third to one-fifth of yields obtained in Spain, Italy and Japan. Similarly, the average acre yield of cotton crop in India is, 89 lbs. of lint as compared to 267 lbs. and 531 lbs. respectively in America and Egypt. It is hardly realized, however, that India is a big continent with very divergent climatic conditions and rainfall as compared to countries which register high yields and the total area under the crop in these countries is comparatively small. It will be hardly legitimate to make such a general comparison between countries. So far as can be seen from the published records and from personal knowledge of some important plant breeding centres in the West, the actual increase in *yield* as a result of plant breeding is generally never higher than 20 per cent. This is the figure that has been declared as a workable limit for rice breeding in Japan. If Indian acre yields are still low, the reasons have to be sought elsewhere. India is an old country

and manuring is never practised. The increased yields of strains are masked by the comparatively smaller areas devoted to them. In regions where strains are grown on a larger scale, protected by irrigation and sometimes fertilized, very much larger acre yields are recorded, as for example, Co. 2 cotton tract of Coimbatore and deltaic rice tracts of Madras. In Egypt, cotton yields are high due to irrigation, heavy manuring and silty soils and in America to manuring, virgin soils and protection against erosion. In certain rice areas of Madras where suitable conditions exist, it has been possible to demonstrate that by the growing of improved strains combined with intensive methods of culture, the acre yields can be increased to 3,000–4,000 lbs. per acre, comparable to yields obtained in Japan. I am confident that plant breeding work in India, both from the standard of work and the results achieved, is quite comparable to similar work done in more advanced countries of the West or East.

iii. *Need for improved agricultural statistics.*

In this connection it may be useful to raise the question of the average yields of crops as published in crop statistics. What is the basis of these figures? It is only recently that this question is being examined. Even in the case of cotton where, due to the cotton cess, it is possible to estimate fairly accurately the total output of the country, the figure arrived at by this method differs from the figure given in the statistical reports by over 30 per cent. In the case of other crops, some tests made in isolated centres have shown that the figures vary from those of the statistical reports very considerably. Even the recording of the area under any particular crop has been found to be inaccurate. So far as can be ascertained, the figures of the statistical reports are not of much value. It is a good thing that the Imperial Council of Agricultural Research have taken up the problem of determining standard yields in wheat and rice. A similar investigation is being started for cotton also. Granting that the production is certainly higher than what is stated to be, such increased production should be reflected in a greater well-being of the cultivator, and the question may be asked whether there is any indication to that effect. There is, however, one thing to be mentioned in this connection, namely, that the population of the country has also considerably increased and there are probably other considerations which may be pertinent though beyond the scope of this discussion.

III. Methods of Breeding.

The principles and technique of plant breeding may be briefly described here. Of the three methods mentioned earlier, namely, selection, introduction and hybridization, introduction may probably be left out though there are instances, almost historical, on record, of introduced superior types from one region

to another proving a phenomenal success. Such successes are more an exception than a rule, since it is within the experience of plant breeders that the great range of agricultural and climatic conditions under which a particular crop is grown in different parts of the country has resulted in special local adaptations which naturally limit the scope of such introductions. We can consider the other two methods in greater detail.

i. *Selection in natural population.*

In the tropics, the plant material has not received the intensive study which has been applied to the temperate crops before the ideas of pure lines and Mendelism were brought to bear on the problem. Every crop presents a mixture of types. Sometimes there may be a dominance of one particular type which may amount almost to a condition of purity, but there is enough evidence that such approximation to purity has risen by the suppression of other types by natural agency. The type best adapted to the prevailing conditions survived, but where adaptation for more than one type is sufficiently close, a mixture of types forms the crop. Selection in such material is nothing but exploitation of the naturally existing variability. Have we any methods to say which primary selections in the variable material would give the desired result? The answer to such a question is, so far as we know, No, and this is the main reason for considering plant breeding as more an art than a science. Intimate familiarity with the crop and the scale on which the selections are made and studied are often the deciding factors in the attainment of success in the method. There is no known method of discriminating the important environmental influence on the crop and the testing of the progenies in replicated and randomized plots is the only criterion to go by. The larger the number of initial selections handled, the greater are the chances of getting a useful type, and for the elimination of undesirable types at the initial stages, the breeder has still to depend upon his visual observations. Although due to the recent advances in statistics as applied to agriculture, designs have been evolved to test even a very large number of initial selections in a replicated experiment, (the incomplete randomized blocks and modifications of the design), still, elimination of a certain number of initial selections without actually bringing them under replicated trials cannot be avoided. Usually the initial yield trials carried out by the plant breeder in smaller plots are later extended to trials in bigger plots under cultivators' conditions in various parts of the tract and the best selection as determined by these series of trials is multiplied and made available for distribution to the cultivators. It has been the experience of the more successful plant breeders that it is not necessary to wait for commencing the district trials until the small scale trials are actually finished, but to

carry on the two trials simultaneously in the later stages. Thanks to the work of the Statisticians, the technique of carrying out the trials has been very much simplified and reduced to a routine. This is in brief the method followed in the selection technique in cereals, rice, wheat, *jowar*, etc. These crops are almost entirely self-fertilized and the initial selection is itself assumed to result in isolating several pure lines and all further work is directed towards determining the best among the several pure lines.

When once pure lines have been established, secondary selection is not usually practised in these crops. It was once tried in rice in Coimbatore to see if there was still genetic variability in one of the established pure lines. Yield was the only criterion that was taken into consideration as there was no morphological variability in the material. Since the variations in yield observed were within the limits of experimental error, it was concluded that it was not worth making secondary selections, in this crop. There are not many records of systematic secondary selection being practised in the cereals and even the few cases mentioned have been carried out more from the point of view of characters other than yield. In cotton on the other hand, secondary selection has always been practised by breeders though, as has been pointed out by Mason (1938), the effect of such secondary selection has been in most cases only of a small advantage while the main improvement has been realized in the primary selection. Such secondary selection has been, until very recently, mainly towards making the selection homozygous, i.e. reducing the genetic variability. In cereals when once a selection is morphologically pure and also reasonably pure for economic characters like duration, height of plant, size of grain, etc., the only point for consideration was yield. In the case of cotton, however, though yield continues to be the main consideration, attention is devoted to two other important characters, namely, length of the fibre and the ginning percentage. These two quantitative characters, to be mentioned again later, are controlled by a number of Mendelian factors and it is impossible to get absolute hymozygosis for these characters even after several generations of selfing. Secondary selection has been mainly directed to reduce the heterozygosity in these two characters to the minimum, and carry forward such of these selections as are apparently pure.

It will be seen from the above that the main principle of selection, namely, exploitation of the naturally existing genetic variability, is not lost sight of in the case of making secondary selection. Hutchinson and Panse (1937*b*) have found out that environmental effects contribute so much to the variability of the breeding material that genetic effects remain undetected by the usual method of progeny row method and have improved the technique enabling comparison to be made

of genetic effects freed from environmental disturbances. The principle of secondary selection is based on the existence of genetical variability, and the attempt of the plant breeder should be to obtain a progressive improvement in his material by the isolation of superior types arising by segregation in the progeny of initially heterozygous selections. The new replicated progeny row technique developed by them helps the breeder to divide the best of his material into two lots, one in which further selection is likely to be profitable, and that which has reached the limit and may be passed on from the breeding to the testing plots. The technique has been used successfully in cotton breeding in Indore and a type with a better quality has been evolved from a strain that was considered under the previously known methods of breeding to be already fixed for that character. In addition to improvements in yield, this technique has also proved highly useful in developing cotton selections showing high field resistance to the fusarium wilt. From material which showed a mean field mortality of 60 per cent. due to wilt, strains have been obtained with less than 10 per cent. mortality.

While the value of this improved technique has been definitely demonstrated in the case of cotton, the question remains whether it would be worth applying it to other crops, particularly, the self-fertilized cereals. An attempt was made to use the method in the selection experiments going on at the Indore Institute on *jowar* and linseed. The data so far available have definitely shown that, while there was no sign of progressive improvement in yield by such secondary selection, genetic variability in lodging of straw in *jowar* and in resistance to wilt in linseed was demonstrated.

ii. *Selection in hybrid population.*

We then come to the question of plant breeding by hybridization. When we find that simple selection is not yielding any material of value, it means that there is no genetic variability to select from, and the only recourse left is to resort to hybridization between varieties so that genetic variability would have been produced to give scope for selection again. Although plant breeders did carry on crossing among varieties even in earlier days, the scientific background for the work was provided by the re-discovery of Mendel's Laws in 1900 and which is now a highly developed science under the name of Genetics. Mendelian principles of heredity are so well known that I need not deal with them here. The science of Genetics has been of great value to the plant breeder in that it has given him a clearer conception of his problems and a better understanding of the processes involved in his work. When Mendelism was first brought to light, great hopes were entertained of combining into one plant various attributes coming from different parents. Whether the practical results obtained in economic plant breeding since the

advent of Mendelism have been commensurate with these hopes, there are differences of opinion. The main aim of economic plant breeding is to get greater yields. Using this as the criterion, it is probably a safe assertion to make that the influence of the science of genetics has been much less profound on the art of plant breeding than was expected by the early geneticists. There is, however, one aspect of the genetical knowledge which has produced profound results. The knowledge that physiological characters like resistance to diseases, cold, etc., are also inherited in the same way as other characters have led to the classical triumphs of Prof. Biffen in producing rust resistant wheats and of Prof. Nilsson-Ehle in producing winter resistant wheats and barleys. Even in India this aspect of plant breeding plays an important part and conspicuous successes have been obtained. We need mention only as examples the wilt resistant *arhar* of Pusa, wilt resistant cotton of Bombay, and blast resistant rice of Madras.

A reference to the annual reports of the provincial and imperial departments of agriculture in India would give an idea of the number of improved types that have been evolved by plant breeding and it is not necessary to give a list of them here. It may, however, be worth mentioning some of the most outstanding ones which are now under cultivation very extensively.

Selections in natural populations:—

Rice	..	GEB. 24 of Madras.
		Indrasail of Bengal.
Wheat	..	Numbers 4 and 12 of Pusa.
		8A of the Punjab.
Cotton	..	Co. 2 of Madras.
		V. 434 of Central Provinces.
		P. 289F of the Punjab.
		Sind Sudhar of Sind.

Selections in hybrid populations :—

Wheat	..	Pusa 52.
		C. 518 and C. 591 of the Punjab.
Cotton	..	1027 A.L.F. and Jayawant of Bombay.
Sugarcane	..	Several Coimbatore types like Co. 213, Co. 281, Co. 290, and Co. 419.

iii. *Mixture or Pure strains.*

The question of the utility of growing a mixture of types rather than a single type may be considered. The idea might appear unscientific to persons accustomed to orthodox views of pure lines, homozygosity, etc. Still it will be evident from what follows that the problem deserves consideration. There has been experimental evidence available with plant breeders to show that a mixture of types grown as such, gives a greater yield than the components of the mixture. Simple

isolations of pure types have no doubt proved an improvement over the local mixtures in several crops like rice, cotton, *jowar*, etc., though it is a general experience with plant breeders that such improved types are of limited value beyond the narrow range of conditions obtaining in small tracts where they were isolated. It is more reasonable to assume perhaps that a mixture of types should prove of greater utility over a wider range of conditions. That certain components of a mixture in spite of their poor performance when grown pure, do manage to maintain themselves in a fairly constant proportion from season to season can only be explained by the advantage they get when grown in competition with other types. The Upland cotton of Central India, when grown as a pure rain-fed crop, suffers badly from diseases and is a poor performer but gains in competition when grown mixed with the indigenous cotton. There have been experiments going on for the last five years with growing these two cottons under different degrees of competition and while the results as regards yields are variable there is a definite indication that the Upland cotton gains by competition effects from the indigenous. There was, however, one consistent result obtained in all the years, namely, that the American in the mixed crop suffered less from leaf-roll and red-leaf than as a pure crop. There was also an indication of the indigenous cotton suffering less from wilt (fusarium) in a mixed crop.

It might be worth mentioning here that there is experimental evidence to show that mixtures do contribute to better spinning quality. For the last two seasons, the material from the experiments with mixtures at Indore has been examined by the Director of the Technological Laboratory, Bombay, and as the figures given below would show, the mixture has a higher spinning value than the average of the two constituents, sometimes even approaching the value of the better of the two constituents.

Spinning values (highest standard Warp Counts).

Mixtures.	1937-38.			1938-39.		
	Actual.	Average of constituents.	Difference.	Actual.	Average of constituents.	Difference.
M9* + M.43-4	22	19·75	+2·25	16·5	17·25	−0·75
M9 + V. 434 ..	25	22·50	+2·50	21·0	19·50	+1·50
M9 + M.U. 4 ..	20·5	19·0	+1·50	24·0	22·50	+1·50

* M9 .. An arboreum strain evolved at Indore.
M. 43-4 .. Another arboreum strain under study at Indore.
M.U.4 .. An Upland cotton strain under study at Indore.

That fairly consistent results are obtained over two seasons and that similar results have also been obtained at the experimental mill, Egypt, (Hutchinson, 1938*b*) show that the mixtures are in no way a disadvantage from the spinning point of view. Even granting that the growing of mixtures is proved to be more profitable to the cultivator, there are several practical difficulties in giving effect to the findings, but still such difficulties should not preclude the breeder from examining the question.

IV. Development of Genetical Science.

i. *General.*

In the early years of genetics, all attention was concentrated on crossing two types, observing the ratios in which any particular character or characters were appearing in the F_2, and deciding that the character or characters were controlled by a single factor, two factors, complementary factors, duplicate factors, etc. Any inheritance phenomenon of a complicated nature was usually ascribed to multiple factors and laid aside. The results all tended to nothing beyond the confirmation of the universal applicability of original Mendelian laws and their later extensions. The second phase of the development of the science of genetics was the study of the chromosomes and the unassailable evidence produced that they are the carriers of hereditary units or genes. All genetic evidence accumulated so far indicates that the gene offers an efficient mechanism for the evolutionary progress of living organism. Studies on the morphology of chromosomes and the irregularities in their behaviour have been used to determine linkage groups and changes in the inheritance of characters and their linkage relationship. There are some aspects of cytological research which are of great interest and importance to particular breeding problems, as for example, the chromosomal interpretation of species relationship, the conception of polyploidy and the explanation of sterility and peculiar forms of inheritance. Breeding programmes involving wide crosses between species or even genera are based upon the results of cytological research. The use of physical agents like X-rays, radiation, heat, cold, etc., has been brought into play to produce by artificial means changes and disruptions in the composition of chromosomes producing mutations more abundantly and at a quicker rate than what were occurring in nature. More recently alkaloids like colchicine has been used to double the chromosome complement of an organism and thus make a sterile hybrid fertile. The advances in these branches of science, genetics and cytology, have no doubt had their effect on plant breeding. Hudson (1937) in his excellent review has brought together the cases where such advances have been made use of. The

advances in the two branches which had remained entirely distinct through much of their developmental history are all converging to a common synthesis and understanding. One going through the literature on genetics that is appearing in recent times, will be really stunned at the progress that has been made. This progress, however, has not been of help to evolve plant breeding methods, but the plant breeder has still to keep abreast of the advances in genetics and cytology and try to incorporate the precepts in his own work so that he can have a greater control over his material.

In the field of breeding horticultural and vegetatively propagated crops, the value of new genetical and cytological techniques is appreciated and in attacking breeding problems full use is made of the latest advances in those branches. The recent work on potatoes may be mentioned in this connection. The only agricultural crop, where an effective collaboration between geneticists and plant breeders has resulted in results of practical value, is maize in America. It is in the breeding of self-fertilized crops that the value of such advances has not become as apparent as one would wish it to be.

ii. *Genetical work in India.*

The actual position of the work in India in the light of the advances mentioned above may now be considered. Although actual plant breeding has produced tangible results of economic value, probably even more tangible than one would expect from the time and money spent on it, it must be admitted that the latest advances in genetical science have had no appreciable effect on this output. It was mentioned earlier that the first phase of genetical science was the phenomenon of segregation. If we look into the published papers in India within the last 25 years (1910–1935), there have been over 200 publications dealing with the inheritance of characters in crop plants. A large majority of them deal with the simple question of Mendelian ratios. It is only a few that might be considered to go beyond the question of simple ratios. It is known, however, that characters like yield itself and those that contribute to it, as for instance, the number and size of the ear in cereals like rice and wheat, and ginning percentage and lint length in cotton, to mention only a few, are quantitative in their inheritance and controlled by numerous genes each probably having a small effect and impossible to distinguish in the later generations of a cross. Genetical analyses on these characters are hard to follow because of their complex inheritance. Recognition of genotypes which is essential for the usual genetic analysis is generally very difficult as they cannot be separated from environmental fluctuations. Eye judgment in many cases are quite inadequate and simple empirical tests are not always available for isolating

all genetic variants. The inheritance studies on such quantitative characters have therefore not received as much attention as they deserve.

The actual genetical contributions in India are from those who are practical plant breeders, and crop botanists working in the departments of agriculture, provincial and imperial. Their work is circumscribed by the immediate and pressing need of producing an improved strain of a crop, the introduction of which would bring a greater return to the cultivator. The material they set to work upon was the crop grown in the cultivators' fields which was an untouched and richly variable population, and simple selection had given very encouraging results. Almost all the improved strains that have been given out to the cultivators are such simple isolations. By the very nature of the material dealt with, and due to local adaptations, the strains so evolved with rare exceptions, as for example, GEB. 24 rice and Co. 2 cotton of Madras, are necessarily limited in their usefulness to the particular areas in which they were isolated. This naturally led to the decentralization of plant breeding research, which was originally confined to a central station in each province, and a number of small breeding stations one in each of the important tracts of the crop, were opened where the crop of that locality could be studied. This is the experience in provinces where plant breeding work has been going on for a longer time, as could be seen from the number of rice breeding stations in Madras and the number of cotton breeding stations in Bombay and Madras.

The earlier hybridization work that had been undertaken was intended to combine in one individual valuable attributes from one or more types and though the breeders did have a clear idea of what combination they wanted to achieve, the knowledge about the inheritance of the characters, they wanted to combine, was however lacking. Such hybridization programme was more or less a hit and miss method and if any success had been obtained, it was more an accident. The crosses were, however, useful for studying the inheritance of some of the easily distinguishable qualitative characters and most of the publications deal with such inheritance. This is practically the position, at any rate, with some of our most important crops like rice, cotton and wheat. In millets, where selection and genetical studies have been of a more recent date, almost all the publications deal with such Mendelian ratios and breeding for special yield attributes is still in its infancy.

Selection work, whether from a naturally variable material or from hybrid populations, was probably considered a mere routine which anyone with elementary knowledge of genetics could undertake. This might be true to some extent because of the nature of material one is dealing with in a country like India. That still greater achievements in plant breeding have not been

recorded in India, might be attributed to the fact that the nature of the material available to the breeder was not correctly understood and too much emphasis was laid on purity of character, morphological and economical. It is desirable for a plant breeder to have a sound knowledge of the advances in genetics and cytology though he may not yet be in a position to utilize all such knowledge in his every-day work. That more tangible results have been obtained in some provinces than in others might be partly attributed to the fact that breeding work was carried on side by side with genetical studies and also perhaps to better technique employed.

V. Genetics in Relation to Plant Breeding.

i. *Quantitative inheritance.*

The advance in genetics as applied to the quantitative characters and what influence this is likely to have in plant breeding technique is dealt with here. It is true that new conceptions of multiple factors, quantitative inheritance, transgressive segregation, factor combination and inhibition have been invoked, but these have helped but little in practical plant breeding. The study of the inheritance of quantitative characters is intimately associated with applied mathematics and it is this that has practically scared away earlier geneticists and plant breeders from undertaking such studies. The application of statistical methods to living things is known as biometry and has developed into an important branch of biological investigations. Biometry is a necessary mathematical tool for dealing with the inheritance of quantitative characters and no modern geneticist can make much progress without a good grasp of this branch. As was pointed out in an earlier section, the variations on which breeder has to work are of two kinds, environmental and genetic, and it is only when the latter component forms a substantial portion of the total variance, selection can be effective and the problem he has always to face is to reduce the environmental variance to the minimum by suitable technique. In the case of hybrid progenies, the classical method of selfing and selecting from F_2, F_3 and so on, has been the chief method followed and has proved successful in cereals, wheat, rice and also in cotton. As practical examples of successes in this line are rice strains evolved combining yield and strength of straw, yield and resistance to paddy blast, and yield and shorter duration, etc., in Madras. Similarly, the case of strains evolved recently by the cotton specialist, Coimbatore, combining yield and fine and long lint in Cambodia cotton may be mentioned. But such achievements have been brought about not with the definite knowledge of the inheritance of the particular characters whose combinations have formed the end in view. Can the geneticist

suggest more rational methods of what to select and how to select in the hybrid progenies and give information on the genetic variance involved in the different generations starting from the F_2? A beginning has been made at Indore to answer these questions with regard to cotton and I should refer to the work of Dr. V. G. Panse who has just published the first results of this study (1930*a*, 1940*b*). Because of the special statistical methods involved, the work was carried out with the suggestions and guidance of Prof. R. A. Fisher. The quantitative character studied was lint length which is one of the important and at the same time complex character in cotton, in crosses among *G. arboreum* types.

He has shown from theoretical considerations that the genetic portion of the variance in a population can be estimated by growing a set of progenies from individuals belonging to that population and taking the regression of progeny means on parental values. This is an important result, for, as has been stated before, the capacity of a population to show immediate response to selection depends on its genetic variability. The genetic variance in the F_2 population of crosses between C. 520, Malvi and Bani was estimated and is shown below:—

Cross.		Total variance in F_2.	Genetic variance.	Non-genetic variance.
C.520 × Bani	..	3·015	1·543	1·472
C.520 × Malvi	..	3·273	1·576	1·697
Malvi × Bani	..	2·416	0·375	2·041

In the first two crosses, nearly half of the variance is genetic, but in the third cross it is only fifteen per cent. of the total variance. While the bulk of the non-genetic variation would be environmental, the presence of dominance and other interactions between factors would also contribute to it. The effect of non-genetic variability, whatever its source, would be to retard the progress made by selection.

In populations with the same amount of genetic variability the degree of improvement achieved by primary selection will also be the same but the response to secondary and later selections will be determined by the genetic constitution of the character, namely, the magnitude and number of factors involved and their dominance and epistatic relations. With only a small number of factors, the possibility of further improvement by selection will soon be exhausted, whereas with a larger number, selection can be continued profitably much longer. As the variation is continuous and the individual genotypes cannot be recognized, unlike in simple qualitative characters, only a statistical approach is available to study these questions. It does not mean, however, that the estimation of genetical variance and

the number of Mendelian factors involved will straightaway solve the difficulties of the breeder, but if genetics is to play its part in the art of plant breeding such studies are essential.

ii. *Heterosis.*

It is within the experience of every plant breeder that the first generation hybrid is more vigorous than the parents and such vigour disappears gradually in successive generations, and it is to this phenomenon that the term heterosis has been used. We need not go into the theory of heterosis, but it is enough to state that the problem of heterosis is the problem of the inheritance of quantitative characters. The heterosis effect has been demonstrated in crops with regard to several economic characters and the greater the gap in the relationship between the parents crossed, the greater the expression of heterosis. Can the plant breeder make use of the heterosis in his work? In vegetatively reproduced crops like sugarcane and potato, when once the cross has been made, the vigour associated with the hybrid can be maintained almost indefinitely. In cases where hybrid seeds can every time be produced in sufficient quantities to raise a field crop, the phenomenon is of benefit even in crops with sexual reproduction. This has been possible in maize and the advance in maize breeding in U.S.A. is nothing but the exploitation of this principle. Hybrid maize is the most outstanding example of the influence of theoretical scientific research in revolutionizing the production practices of an agricultural crop. The same principle is being applied recently to breeding sugar-beet crop in Sweden. The only grain crop of India in which the breeding principles applied to maize, can be used is *bajra* (*Pennisetum typhoideum*), but no serious breeding work has yet been taken up in this. In breeding self-fertilized crops on the other hand, the expression of heterosis in any considerable magnitude is bound to arrest progress in selection. In the example of the cotton cross discussed in the previous paragraph, the portion shown as non-genetic variance would include the effect of heterosis. It must be stated in this connection, that it is so difficult to analyze the non-genetic variance apart from the fraction due to environmental effect into components due to dominance, heterosis, epistacy, etc., as they are all interrelated to each other.

iii. *Physiological and Genetic Correlations.*

Another aspect of genetics in which more critical research should prove useful to the plant breeder, is with reference to characters that show physiological or genetic correlations. It must be within the experience of every plant breeder that selection for improvement on a particular character results in improvement only up to a point. Beyond that, gains are compensated by depreciation in other characters. There is evidence

of several physiological correlations in crop plants like cotton, rice, and wheat. In developmental studies with cereals like rice and *jowar* in India, the correlation between yield and other characters like size of ear, height of plant, tillers, etc., have been extensively studied and recorded. To discuss a few of these in rice, the height of the plant is very highly correlated to duration (Ramiah, 1933) so that as a general phenomenon, late duration varieties are likely to be taller than short duration ones. Naturally this would set a limitation to obtaining a very short stature type with a long growing period and *vice versa*, though there is likely to be a wide margin for variability in height or duration within the two groups considered separately. Similarly, a correlation is found to exist between yield and duration in the rice crop which may vary anything from 3 to 8 months. Generally under South Indian conditions the best yielders are those that have a medium duration of, say, 5 to 5½ months. Though varieties of shorter duration, 3 to 4 months, are sometimes found to give high yields of 3,000 to 4,000 lbs. of grain per acre under particular conditions of soil and climate, they are generally not so heavy yielding as the later duration types. Varieties of over 6 months in duration, which people are obliged to grow because of certain special conditions in a particular tract, are generally also not very heavy yielders. That this relation is physiological can be seen from the series of experiments that have been conducted with them in Madras (Ramiah, 1937). Since these long-duration varieties are generally season limited, any reduction in age beyond a certain minimum brought about by unseasonal planting reduces their yield potentiality. Now the question is whether a very high yield associated with a variety of, say, 5 months' duration can be combined with an early duration of 3 months. Experience in Madras would appear to show that breeding for such an end in view should prove a waste of time and effort. There was an interesting case in rice where an attempt to combine a packed arrangement of the spikelet on the panicle with a medium size of the grain ended in failure (Ramiah, 1931*b*). The close packed arrangement was always associated with a small grain. The correlation here may be either physiological or simply structural. The case of the cross in rice to combine panicle length and clustering of spikelets may also be mentioned. Combination of length in the panicle with the clustering of the spikelets proved impossible (Ramiah, 1931*b*, l. c.).

There are more chances of the breeder achieving his end, if the character combinations he is after, are genetic rather than physiological. In the case of cotton, within *G. arboreum* species there are types with very high ginning percentage, but with lint of very poor quality, and types with poor ginning but with finer and longer fibre. The cotton breeder would like to combine these two characters as high ginning and longer fibre both contribute to a better price being obtained by the cultivator

for his produce. Though critical evidence is lacking, it may be stated from the results of breeding data available, that it is not possible to combine the two characters beyond a certain limit. To get critical data bearing on the point, an experiment has been going on for the last three years in Indore which may be referred to here. In the F_2 population of the crosses between C. 520, Malvi and Bani, plants with the highest and lowest values of ginning percentage and with the highest and lowest values of lint length were selected and F_3 progenies grown from these. The correlation coefficients between the mean values of the progenies for ginning percentages and lint length are:—

C. 520 × Bani	..	−0·254
C. 520 × Malvi	..	−0·425
Bani × Malvi	..	−0·286

All the three coefficients are negative but insignificant. The combined correlation coefficient is −0·324, which just falls short of significance on the 5 per cent level. This small negative relation between ginning percentage and lint length is reflected in progenies selected for high ginning percentages having a slightly lower lint length than those selected for low ginning. It is probable that this negative association is genetic rather than physiological, because no such consistent relationship is observed between the ginning percentage and lint length of the individual parental plants of these progenies. The fact that the processes of lengthening and thickening of the cotton fibre do not take place simultaneously also supports the conclusion that the relationship is not likely to be physiological.

Cases of several correlations between morphological and quantitative characters have been recorded in cotton and rice and to have an idea of the scope of such correlations the following few may be mentioned here :—

Cotton :—between corolla colour and lint length; between corolla colour and lint index (Hutchinson, 1931); between red plant body and length of vegetative period (Leake, 1914), and lint colour and lint length (Kottur, 1923).

Rice :—between sterility and growing period (Ramiah, 1931*a*); between anthocyanin pigment and yield (Ramiah, 1933 l. c.); between anthocyanin pigment and tillering (Ramiah, 1935) and between colour of grain and weight of grain (Parnell *et al.*, 1922).

Such studies in other crops should prove very useful to the plant breeder.

iv. *Use of 'Discriminant function'.*

In very recent times the question of the use of 'discriminant function', first suggested by R. A. Fisher (1937) in plant breeding

has been brought in. The only paper we have relating to the subject is that of Fairfield Smith (1937) which relates to wheat and he comes to the conclusion that with a number of lines derived from a 'composite hybrid mixture', initial field selection for yield might be made on the basis of the size of the grain. In simple language the principle may be explained as below. In every crop the yield could be divided into a whole set of different features as for example, the number of ears, the number of grains per ear and the weight of the individual grain in cereals like rice and wheat. The analysis of yield might show that certain of these attributes are more variable due to environmental conditions than others, and in basing selections for yield, more weight should be given to such an attribute that shows less variability due to environment. The principle is perhaps not new as the developmental studies initiated by Prof. Engledow in Cambridge did take into consideration the yield attributes in making selections, but no systematic experiment has been made on the points. In rice breeding also such attributes of yield as tillering, ear size and grain size have been used successfully. A necessary requirement for the use of a discriminant function is experimental data to determine what measurements are least affected by environmental fluctuation. In cotton for instance, there are several characters which are components of yield such as bolls per plant, seed cotton per boll, seeds per boll and lint per seed. Though from experience it may be stated that some of the above attributes like bolls per plant were much more variable than others, an attempt is being made in Indore to get experimental data to see how far we can use the 'discriminant function' in cotton breeding.

v. *Wide Crosses.*

The problem of the wide crosses and study of the range of variability in crop varieties may be considered at this stage. This has come to the forefront because of the work of Vavilov and other Russian botanists and because of the great advance made recently in the study of polyploidy. One often hears of the necessity to have a wide collection of types for use in breeding. So far as India is concerned, the point has got its possibilities as well as its limitations. For instance in cotton, India being itself the home of one of the most important species *G. arboreum*, with several secondary centres of origin (Hutchinson and Ghose, 1937*a*), there is nothing probably to be gained by bringing in new collections from outside so far as this species is concerned. But the demand for producing better quality cottons in India is sometimes considered capable of solution by the increase in the cultivation of Cambodia or Upland cotton (Ramanathan, 1938). All the types of this cotton that are now being grown extensively are the relics or acclimatized types of Upland Americans introduced from America in earlier years. Selection

from the introduced types of America has not been very fruitful. No material from the original source with plenty of genetic variability has been tried and it is possible that in its original home types may be available that may prove suitable to tracts in India which do not grow this cotton now. It is from this point of view that an extensive collection of material from the original source might prove of interest. Similarly, intensive attempts by breeders to improve *G. herbaceum* cottons of India have led to the same inference that material from outside India should be introduced (Ramanathan, 1936).

With regard to rice, there is plenty of variability to be found in the various parts of India and there appears to be no justification for introducing variable material from outside. There are still several unexplored regions within India itself and work in Coimbatore has shown that such exploration is bound to give the breeders new species, still undetermined, which may be useful to them. The importance of wide crosses particularly with wild types is receiving increasing attention and the results of such work elsewhere and in India too have been useful in introducing into the cultivated types, characters such as hardiness and resistance to diseases which are usually present in wild forms. From this point of view, collection of wild types is certainly desirable and it has proved of practical importance in sugarcane already. Similar results are expected in potato also. Exploration of wild types particularly in the improvement of fruit has not received any attention it deserves in India, though North East India is known to be the original home of certain citrus types.

Though there has not been much of genetical work as related to wide crosses in India itself, workers in India have not failed to make use of the knowledge accumulated elsewhere in attempting wide crosses. More from the scientific point of view, some years ago a programme of crosses between different species of rice was undertaken in Coimbatore. Some of them had proved of cytological interest and in throwing light on the phylogeny of rice (Ramanujam, 1938), (Parthasarathy, 1939). It is interesting to note that the progenies of one interspecies cross *O. sativa* × *O. longistaminata* has given some material of economic value. In one of the papers contributed to the agricultural section of this year (Sreenivasan *et al.*, 1941) is recorded the obtaining of drought resistant strains from the above cross. It is quite likely other interspecies crosses might also give useful breeding material.

Regarding interspecies crosses in cotton though crosses within the Asiatic species and within the New World species are practicable and have been extensively tried, there is no record to show of any valuable material having been obtained from such crosses. Harland's work (1932) has shown that crosses can be effected between the two Asiatic species and between the

two New World species, but homologous characters are built up in such widely different ways in them that the genetic balance is usually disintegrated by segregation in F_2 and later generations. He has, however, shown (1936) that it was possible to transfer single genes or small groups of genes from one species to the complement of the other, but not breeding of intermediate types. This is achieved by the technique of repeated back crossing and one of the recent cases where a success has been reported (Knight and Clouston, 1939), is a cross between *G. hirsutum* × *G. barbadense* where the resistance to 'blackarm' in one of the strains of the former has been transferred to a type of the latter using the above technique. The crosses between the Asiatic and American species are still wider since they involve differences in chromosome number as well. But even such wider crosses have not scared away plant breeders and have been made in Russia and recently in India as well (Amin, 1940). The knowledge about the use of colchicine in doubling chromosomes has encouraged these attempts and since the work is still in an experimental stage, nothing can be stated definitely about its economic possibilities.

In fact, the lead in the attempt at wide crosses has come from India particularly in sugarcane, due to the enterprise of Rao Bahadur Venkatraman. He has succeeded in making such wide crosses as between sugarcane and sorghum and more recently even between sugarcane and bamboo. The latter work, though still in its infancy, appears to show enormous possibilities of improving the sugarcane crop. It must be remembered, however, that sugarcane is a vegetatively propagated crop and the difficulties of further selection are absent.

In rice where all the cultivated forms are grouped under one single species with the same chromosome number, there are geographical races which differ in their chromosome make up. Crosses among such races are possible and have been repeatedly made in spite of initial difficulties in several cases, but still there is no record of any considerable practical success having been obtained by such crosses anywhere. The case is, however, different in cotton where different races of *G. arboreum* and *G. herbaceum* exist with the same chromosome numbers and hybridization among them within the species has given results of practical value.

vi. *Limitations in wide crosses.*

With our present assumption of a large number of genes controlling quantitative characters, one should expect to get all possible combinations of characters in the F_2 and later generations provided, a sufficiently big population is grown of them. Recent work by E. Anderson (1939*a* and *b*) on the point is very illuminating. He has shown by experimental data in a species cross in tobacco that, however manifold the recombinations might

seem, they are in reality but a small proportion of the possible recombinations of the parental species. He discusses the powerful restrictions to character recombination in F_2 under four heads: gametic elimination, zygotic elimination, pleiotropy and linkage. Every plant breeder must be quite familiar with gametic and zygotic eliminations in crosses between species or races which manifest themselves by pollen sterility and non-viability of seed produced. The question of pleiotropy where a single primary effect of a gene results in manifold effects on the development of the plant has not received as much attention as it probably deserves. Recently we have been studying in Indore the pleiotropic effects of one of the genes that is responsible for lintlessness in cotton. The homozygous lintless type is a much shorter plant with suppressed internodes, somewhat late in maturity and with a definitely different growth rate as compared to the linted type. The lintless type has also shown variations in its survival according to the environmental conditions. The large number of genes controlling quantitative characters located in the various chromosomes should, as shown by Anderson, be closely linked because of the restricted number of crossovers possible in the chromosome. It is definitely proved that in spite of the variations from plant to plant in the hybrids as a group, the characters of the parental species or races tend very strongly to stay together. The above findings have an important bearing on plant improvement. In this connection mention might be made of a serious effort made in Coimbatore over a series of years to obtain a valuable combination of characters found in different races of rice. One of the types originally imported from Java had a special characteristic of very long ears, about twice the length of any to be found in the local types but the length was compensated in this variety by extremely poor tillering, i.e. fewer heads per plant. The attempt made was to combine the ear length of this variety with a greater number of smaller ears in another standard strain. The cross was carried on up to F_9 and F_{10} selecting from each generation in the usual way and ultimately when the final selections were compared against the local strain, they failed to approach the yield of the latter. It is known that tillering and ear length must be controlled by several factors and the failure of the attempt to synthesize this desirable combination only shows that such a combination, high ear number of one parent with the length of the ear of the other parent did not occur in the cross. We should probably have been content in this cross with an intermediate tillering and intermediate size of ear. As Anderson has pointed out the most efficient way of achieving the desirable combination would have been to make crosses among selections which are most like one of the parents in ear length with those which are most like the other parent in ear number. In this connection another interesting cross in rice which has been

attempted in the United Provinces might be mentioned (Sethi *et al.*, 1937). The problem of rice fly infestation is important in this tract and trials are being made to get over the difficulty by producing types with enclosed earheads by crossing the ordinary type with another *sathi* type, where the earhead remains enclosed inside the leaf-sheath (cleistogamous). The *sathi* rice is a very poor yielder and has a coarser grain, but cultivators grow it for this one character of its escaping the attack of ear fly. The cross has been carried up to F_8 or F_9 generation and types with enclosed ears have been obtained which are an improvement over the *sathi* rice, but not comparable to the normal type in yield. The inheritance of the enclosed ear type has been studied and found to be of the multiple factor type and it is quite possible greater progress might be achieved by crossings among selected types, those *approaching* the *sathi* parent in ear character and those *approaching* the normal type in yield from the hybrid generations. This is probably a definite case where advances in genetical knowledge could be put to practical test in economic plant breeding.

VI. Maintenance of Purity of Strains.

The question of the deterioration of strains once fixed and released for distribution to the cultivators might be considered. It is a usual complaint from cultivators that a strain, though known to give a good performance to begin with, deteriorates after a period of time. Such deterioration where it is proved to exist may be either due to non-genetic or genetic causes. In spite of the fact that sugarcane is a vegetatively propagated crop, the deterioration of the Coimbatore types intensively cultivated in the United Provinces can, from the data available so far, be shown to be due to greater incidence of pests and diseases because of the faulty agricultural practices, namely, the growing of the crop repeatedly without sufficient rotation in exhausted soils. In the case of self-fertilized cereals like rice and wheat, so far as simple (selections) pure lines distributed by the Departments are concerned, there is no evidence of such deterioration. Once, seed of a strain of rice (GEB. 24) in Madras was obtained from the district where it had been distributed four years previously and in an experiment at the central station no sign of deterioration could be found. It must be pointed out, however, that the seed was to all practical purposes as pure as the seed of the experimental station itself. A similar result was obtained in Coimbatore with regard to Co. 2 cotton strain (Ramanathan, 1937). Dr. Shaw (1935) mentions a case where one of the Pusa strains of wheat had been declared to have deteriorated, but he found the seed obtained from the locality to have been badly mixed up with other types. Fairfield Smith (1938) has mentioned a case in America where

some of the wheat strains from Turkey Red Wheat which were very much better than the control to begin with ultimately came down to the level of the control after some years. While deterioration due to the strain getting mixed up with other inferior strains in the course of cultivation by growers is beyond the scope of the breeder's work, deterioration due to genetical causes comes within the breeder's purview. In the case of cotton when once a strain has been released for distribution, the only thing we know is that the genetic variance has been reduced to such an extent as not to be detected by ordinary methods of plant breeding, but there can still be sufficient genetic variability left in the material which can exhibit itself in course of time. Though experimental proof is not available, it is possible that in quantitative characters controlled by a very large number of genes, there may be small mutations (East, 1935) and such mutations can result in deterioration. If the residual genetical variability left in the strain is such that the strain consists of genotypes some slightly better than others, deterioration can result by the gradual increase of the poorer ones. By the adoption of a small replicated progeny row test at the breeding station every year, we can weed out poorer genotypes from the material. Such deterioration due to genetic causes is known to exist even in self-fertilized cereals where the strains are from hybrids. Such strains are known to throw 'off-types' after some generations (Engledow, 1933) and the gradual deterioration in this case might be attributed to a residuum of impurity and the decreasing percentage of heterozygosity from generation to generation. In progenies of wide crosses such 'off-types' might occur due to cytological causes, losses in chromosome segments or even whole chromosomes (Love, 1939). It follows therefore that a well-organized scheme of seed multiplication and distribution must be continuously kept up. A nucleus must always be maintained at the breeding station to form the primary source for multiplication. The Cotton Committee have recognized this principle and are actually financing schemes for maintaining nucleus of cotton strains evolved at the breeding stations.

VII. Organization of Genetical Research.

In the preceding pages a brief outline of the plant breeding and genetical work in India has been given and indications made in what aspects the advances in genetical science can influence plant breeding practices. Plant breeding as has been pointed out already has a definite utilitarian end in view, namely, that the cultivator must get something more than what he gets now by growing the new variety put out by the plant breeder. This is, in fact, the touchstone for the ultimate success or failure of any plant breeding programme. The attempt

of the breeder to find something better than the existing one is, from its very nature, a never-ending scheme and hence the research has to go on continuously. Unlike other aspects of agricultural research, plant breeding work is capable of giving returns, several times that of what is actually spent on it and there is also the additional advantage of the results of plant breeding research being taken up readily by the cultivator as it involves no additional expenditure on his part.

Though the advances in genetical science have come mainly from the work in organisms of no economical value like *Drosophila*, *Oenothera*, *Datura*, etc., so far as India is concerned, the little genetical work that has been done is all related to agricultural crops. A great deal of genetical work even in these crops yet remains to be done. While part of it may be of practical value, it may include also other aspects which would simply add to our knowledge of these crop plants. The latter might be called basic research in genetics, and there must be some organization to carry on this work. The crop botanists of the provincial departments of agriculture have always got the pressing problem of producing improved types by ordinary breeding to replace existing types of crops and all of them cannot undertake problems of basic research either for want of time or want of facilities. Autonomous bodies created for individual crops like the Indian Central Cotton Committee for cotton have recognized the importance of such basic research. This body is financing a genetics research scheme in cotton. This basic research carried on at Indore is concerned mainly with one aspect, namely, research that has a direct bearing on plant breeding technique. The Jute Committee which has recently come into existence is expected to do for jute what the Cotton Committee is doing for cotton. The imperial department of agriculture formerly at Pusa and now in Delhi is doing a considerable amount of plant breeding work of practical value and also a certain amount of basic research on genetics of crops. The Imperial Council of Agricultural Research is the other body created as a result of the recommendations of the Royal Commission on agriculture that can arrange to see that such basic research in crops is carried on. The finances available with this body have been rather limited previously, but due to the passing of the Agricultural Produce Cess Bill recently, there is likely to be considerable improvement in the near future. This body has spent during the last 10 years (1929-30 to 1938-39) a sum of about 25 lakhs of rupees on crops generally, including all aspects of research besides another sum of about 16·5 lakhs on sugarcane alone. Of the former amount, nearly 50 per cent. has been devoted to financing schemes of rice research in provinces. This amount spent by the Imperial Council of Agricultural Research on crop research is in addition to what the provinces and States are

spending from their own budgets. It will still be worth mentioning that what is spent on this research in India, considering the size of the country, variety of crops and problems, will not compare favourably with what is spent on similar work in countries like Japan and Egypt. Towards plant breeding and genetical research, the former spends about 28 lakhs of rupees and the latter 5 lakhs of rupees annually. Looking into the nature of the schemes financed by the Imperial Council of Agricultural Research with regard to crops, with the exception of a few which can be termed basic research, the majority of them are of a routine nature, ordinary plant breeding schemes. Some of them are schemes either on new crops, for example, fruits, where no systematic work had been done previously or on crops which certain provincial departments of agriculture had not done any work on previously in spite of their importance to them. With regard to rice, a certain amount of basic research has been done under the schemes, but the bulk of them have dealt only with problems of local interest, namely, evolving improved strains out of local varieties in the provinces. Even the programmes of basic research, I am referring only to genetics here, have not generally been on any preconceived and co-ordinated plan. There is no doubt that with greater co-ordination, more valuable results might be achieved. One example of what a good co-ordinated scheme of basic research can be, might be mentioned from America. Maize (corn) is the most important cereal of the country, perhaps not more important than rice to India, and every University or State Agricultural College is doing some work on the crop. In 1928, Corn geneticists initiated a systematic study in which each of the 10 chromosomes of Corn was assigned to workers in different institutions. This co-ordination of effort has eliminated much duplication and has speeded up the research programme to a remarkable extent. The inheritance of over 350 genes has been studied and their position in individual chromosomes has been determined.

Due to the initiative of the Imperial Council of Agricultural Research, methods of describing crop plants from the genetical point of view have been standardized with regard to the two crops, cotton and rice (Hutchinson and Ramiah, 1938*b*), and similar work is in progress with regard to other crops also. When the available material has been actually described according to the methods prescribed, it should go a long way in helping the breeder to understand the material available with his colleagues in other parts of India.

When the problem of plant breeding work in India was discussed before the Crops and Soils Wing of the Board of Agriculture in December, 1937, it was considered that plant breeding research may have to be carried on at several centres particularly in crops with limited adaptibility, examples rice and cotton, but that basic research should be confined to one or

two selected centres only. Involved with the question of basic research is the question of crop introduction. The question of the formation of the Bureau of Plant Introduction under the auspices of the Imperial Council of Agricultural Research had already been discussed at two meetings of the Board of Agriculture, 1935 and 1937, and the principle has been accepted. Now that the finances of the Imperial Council of Agricultural Research are likely to be augmented, the question of the starting of an organization on the model of the Bureau of Plant Industry in United States of America might be considered. This bureau in America which works with headquarters at Washington has got on its staff a large number of eminent men on the different branches of crop research, and such men not only co-ordinate the various items of research in the different States, but also place at the disposal of workers or bring to the notice of workers of achievements in their branches recorded elsewhere. The Bureau is also in charge of the introduction of crops and plants into the country and arrange for their tests in suitable centres in co-operation with individual States. The Bureau also undertakes, whenever necessary, to send individuals and expeditions to various parts of the world to collect material of value for breeding purposes. Will it be too much to expect that a beginning on this model will be made in India?

While the advances in the science of genetics have been dealt with chiefly with reference to crops, the principles are of equal application to animals as well. The principles of genetics have hardly been utilized in the breeding of stock in India and I do not know whether genetics is ever taught to the students of the Veterinary Colleges. There is still another aspect of genetical science as applied to human race. The science of biometry in its application to genetics has been responsible for all our present-day knowledge on human inheritance (Eugenics). I am not sure that sufficient attention is paid to the teaching of eugenics to the students in any of our several medical colleges in India. A rough idea of the development of genetical science along diverse lines can be had from the papers that were contributed to the Seventh International Congress of Genetics held in Edinburgh in 1939. There were 353 contributions grouped as below:—

Gene and Chromosome theory and Cytology ..	61
Physiological genetics	46
Animal breeding in the light of genetics ..	53
Plant breeding in the light of genetics ..	46
Human genetics	51
Genetics in relation to Evolution and Systematics..	52
Statistical genetics	17
Genetical aspects of growth—normal and abnormal	27
TOTAL ..	353

VIII. Genetical Work and Universities.

Before I conclude I should like to say a few words about our Universities. There are seventeen Universities in India, almost all of them having affiliated colleges teaching up to Honours degree in biology but not one can still boast of a chair in genetics. The Honours students in Botany do, I believe, receive a few lectures on principles of Mendelism, but whether they get anything beyond that is very doubtful. Recent advances in genetics have had a profound effect on our knowledge of taxonomy and ecology, but still it is doubtful if students are made to get a grasp of such principles in their taxonomic studies, which, so far as I know, still form a big portion of the botany syllabuses in the colleges. It is a point worth considering whether the taxonomical syllabus should not be cut down a little and the same substituted by genetical studies on agricultural crops. Even in connection with the taxonomical studies in the Universities, botanical excursions to key regions of agricultural crops and plants in co-operation with the crop botanists could be usefully undertaken. There is a wide field for this work in India particularly with our important crops, rice, sugarcane, fruit trees, etc.

There is one branch of botanical research in which several Universities have got competent Professors to undertake and guide research. I am referring to cytological research. From what has been said in the earlier portions of this address, it will be evident that most of the latest advances in genetics have come from cytological research. Still most of the cytological work done in India refers either to the embryosac development in some unimportant plant or determination of chromosome numbers. The plant breeders in the course of their work come across various problems necessitating intensive cytological studies which can easily be undertaken in the Universities. In some cases where crop botanists are making fundamental studies on their crop, they have their own cytological sections, but still I feel that this is a branch of botanical research in which the agricultural departments and the Universities can well co-operate in the interest of maximum output in the country. In recent times there have been a large number of brilliant young men who have gone abroad for intensive cytological studies and returned to India. Surely it should be possible to make use of these men in this work. Even in other branches of botanical research, physiological genetics, for example, such a co-operation between crop botanists and Universities should prove extremely beneficial. I am mentioning the above points not with an idea of criticizing the botanical work in the Universities, but to draw attention to the necessity for a change in the outlook. I am sure the difficulties, if there should be any, against such co-operative work, could be got over by personal contacts of individuals interested in

common problems. The Imperial Council of Agricultural Research, when it was first formed, did have as one of its objects, bringing about a greater co-ordination between agricultural departments and Universities and it has succeeded to some extent in the attempt. Two instances of such successful co-ordination may be mentioned in this connection, namely, the rust work in wheat, and the general statistical work as applied to agricultural experiments. Let us only hope that such healthy contacts between workers in the agricultural departments and the Universities will be brought into effect in an ever-increasing measure, resulting in a greater output of basic research in the country.

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SECTION OF PHYSIOLOGY

President :—B. B. DIKSHIT, PH.D., M.R.C.P., M.B.B.S., D.P.H.

Presidential Address

(*Delivered on Jan. 4, 1941*)

SOME OBSERVATIONS ON SLEEP

I must first thank the Indian Science Congress Association for inviting me to be the President of the Physiology Section this year. It is usual on occasions like this, especially for one whose official designation is a 'Pharmacologist', to say that the invitation was accepted with a good deal of diffidence and hesitation. I had no such hesitation in accepting this honour because I do not think there is any difference between a pharmacologist and a physiologist. Sir Henry Dale, Prof. Otto Loewi, Prof. C. F. Heymans are often designated as pharmacologists and yet they won the Nobel Prize for work in experimental physiology. Profs. A. J. Clark, J. H. Burn, J. H. Gaddum and E. B. Verney are some of Great Britain's distinguished physiologists though all of them occupy Chairs in Pharmacology. Here in India one of my distinguished predecessors, Col. R. N. Chopra, has also been officially designated as a pharmacologist and yet he has contributed more to experimental physiology in this country than any other single individual.

I did, however, hesitate to accept the honour because my own contribution to experimental physiology is limited. Moreover, I have chosen for this address a subject which has its basis on this limited experimental work. I was encouraged to do so by the remarks of our distinguished President of last year, Prof. Birbal Sahni. In the very beginning of his presidential address Prof. Sahni says: 'When a man of science accepts the position of honour in which I find myself this evening it is usually understood that he undertakes, among other things, to engage a large public audience, having the most varied pursuits in life, on some topic of general scientific interest. *At the same time he is expected to have at least something to say that he can claim as his own and, what is more, to say it in plain language.*' I hope that what I am going to say to-day will interest a sufficient number of young physiologists who have assembled here to induce them to pursue these investigations further.

The subject of this address is 'Some Observations on Sleep'. In spite of the immense strides that experimental physiology

has made during recent years, it must be admitted that the problem of sleep remains to this day unsolved. The phenomenon of sleep has, however, been investigated by a very large number of workers from various points of view. Observations on the physiology of sleep have been numerous. Almost every organ of the body has been studied and its relative behaviour in sleep and waking state compared. I do not propose to discuss here the various aspects of sleep that have been studied, important though they are, because such an attempt will require several hours. Most of the literature on sleep is in German, some in French, comparatively little in English. A complete review of the literature before 1913 is given by Pieron in his work 'Problem du Sommeil' and most of the literature in the next fifteen years has been admirably summarized by Kleitman in his monograph on 'Sleep' published in the Physiological Reviews. A very important contribution to the various aspects of the problem of sleep has been made by Viennese School of Scientists in their publication 'Der Schlaf' edited by Sarason. I shall, therefore, refer to the literature only on those points which concern us directly in our discourse this morning.

Physiological changes during sleep

I shall begin by making a few observations on the physiological changes that occur during sleep. I propose to refer to only four points, viz., circulation, respiration, muscular movements and sweat secretion.

(*a*) *Circulation :*

A number of observations have been made on the heart rate and blood pressure during sleep and the generally accepted view seems to be that the rate of the heart and the level of blood pressure are lowered during sleep. Brooks and Carrol (1912) for example observed 127 patients and found that in most of them there was a fall in blood pressure attaining the lowest level 1 or 2 hours after the onset of sleep. It is interesting to note that their patients who were 'resting' but not 'sleeping' did not show the same degree of fall. Similar results were obtained by Mueller (1921), Mac William (1923), Shepard (1914), Landis (1925), and others. A reduction in the rate of the heart has also been observed by several workers. Klewitz (1913) found a reduction of 14·8 beats per minute in the rate of the heart during sleep while Kanner (1926) found it to be 13·2. Lowering of the pulse rate has been observed by other workers also (Weichmann and Bamberger, 1924; Mac William, 1923; Boas and Weiss, 1929). It must be stated, however, that such reduction in heart rate and level of blood pressure cannot be found if sleep is disturbed as for example by dreams.

Although there is a general agreement that the blood pressure falls during sleep, there is no evidence to show that this fall

causes sleep by producing cerebral anaemia. Howell (1897) was one of the early supporters of the cerebral anaemia theory of sleep. Shepard (1914), however, made very carefully controlled observations on patients with trephine holes in the skull and came to the conclusion that there was a significant rise in the brain volume, indicating an increased blood supply to the brain. Kleitman (1928) made direct observations on puppies and failed to observe any evidence of cerebral anaemia. Mac William (1923) expressed doubts about the validity of the cerebral anaemia theory and thought that the slight lowering of blood pressure will be more than compensated for by the change of position from the erect to the horizontal. Recently Gibbs, Gibbs and Lennox (1935) obtained direct records of cerebral blood flow during sleep in man by means of a thermo-electric blood flow recorder and concluded that the onset and termination of sleep did not affect the blood flow through the brain. Therefore, as Landis (1925) observed the fall in blood pressure is rather a resultant of, than causative of, sleep.

(*b*) *Respiration :*

Many observations have been made on the rate and rhythm of respiration and most of the observers agree that respiration is depressed during sleep. Pieron as early as 1913 observed the depression of respiration during sleep. Bass and Herr (1922) found an increase in the CO_2 tension of the alveolar air during sleep, and Hess (1932) thought that the changes in the CO_2 concentration of blood found during sleep would substantially activate the respiratory mechanism in wakefulness, showing an active depression of the respitatory mechanism. Wright (1931) observed that the respiratory mechanism was definitely depressed during sleep and breathing became inadequate to the needs of the body.

Certain changes have been observed in the type of respiration when a person falls asleep. Cheyne-Stokes breathing was observed by Broadbent (1877). Mosso (1878) thought that the breathing became more thoracic and less abdominal. Shepard (1914) supported Mosso's observation while Reed and Kleitman (1926) failed to find any such change. Some of the changes in the type of respiration could be accounted for by changes in position from the erect to the horizontal, but changes in the chemistry of blood evoking no response from the respiratory mechanism is undoubtedly due to the depression of respiratory centres. Kunze (1928) reported an increase of 10% in blood acidity and this increase will certainly stimulate respiration unless the centres are actively depressed.

(*c*) *Muscular Activity :*

One of the important concomitants of sleep is a complete muscular relaxation and lessening of the voluntary muscular

movements. Muscular movements during sleep have been studied a good deal by some simple mechanical device applied to the bed of a subject or a cage of an animal and a record of movements graphically registered. Szymanski (1918, 1920, 1922) obtained a number of such 'actograms' and by recording the activity of different animals divided them into two classes 'polyphasic' and 'monophasic'. According to Szymanski the polyphasic animals have a number of alternating periods of rest and activity during 24 hours. White rats, for example, have ten. They rest for a couple of hours, then wake up and are active and again fall asleep. Rabbits have about sixteen periods of rest and activity during 24 hours. Birds are generally monophasic, active during the day and resting by night. Adult human beings are monophasic but a new-born baby is, like a rabbit, typically polyphasic. It is generally known that the muscles are relatively toneless during sleep, the tendon reflexes are diminished and the plantar reflex may be extensor.

(*d*) *Sweat Secretion :*

References in the literature about the secretion of sweat during sleep are not many. Potzl (1929) mentions that sweat secretion is increased during sleep and quotes Czerny when he says that 'the sweat drops in a sleeping child can be easily seen'. A more detailed study of secretion of sweat in children was recently made by Day (1939). He studied insensible perspiration by the method of weighing hospital children at frequent intervals and found that insensible perspiration was considerably increased and with room temperature about 29°C. visible perspiration was nearly always present at the onset of sleep. Day's studies show a close relation between the onset of perspiration and commencement of sleep.

In this country with the usual warm atmosphere it is a frequent experience to see sweating especially immediately after the onset of sleep. Beads of perspiration are seen over the forehead and neck and many times the whole body is covered with palpable if not visible perspiration. This phenomenon is more commonly observed in children but is present in adults also. It is important to note that the sweating is not due to mere rest alone, for the difference in sweat secretion between a resting and a sleeping individual is quite obvious.

To summarize therefore it is generally accepted that during sleep the heart beats slower, the blood pressure is lowered slightly, the respirations are depressed, muscular movements diminished and the sweat secretion increased, especially immediately after the onset of sleep.

Sleep a Parasympathetic Phenomenon

I shall now divert a little at this point from our main topic and say a few words about the sympathetic and parasympathetic

components of the autonomic nervous system. It is now generally recognized that these two components are concerned in the regulation of the physiological function of different organs of the body, and the part they play is usually antagonistic to each other. It has further been recognized that the sympathetic system is a 'positive regulator of preparedness and activity' while the parasympathetic system 'preserves and economizes energy, protects against strain and restores activity' (Hess, 1932). We are more concerned about the parasympathetic in this discussion and therefore I shall say a few words about it to show how it is always working to economize energy and how its effects are brought about in the defence mechanism of the body. Thus a strong light thrown against the eyes will bring about immediate contraction of the pupils to protect the eyes and this contraction is brought about by the 3rd nerve which is parasympathetic. An irritant gas entering the respiratory passages will evoke reflexes which will result in contraction of the bronchioles and this contraction of the bronchioles is again a parasympathetic action through the vagus. If any undesirable food or substance finds its way into the stomach, it will be immediately vomited out through the influence of the parasympathetic. If it goes further down into the intestines, the body defensive mechanism will try to get it out by producing diarrhoea and this process again is governed by the parasympathetic. An increase in the parasympathetic tone will cause the heart to beat slowly and thus prolong the rest period of the heart. The parasympathetic system is, therefore, always alert in protecting the body against strain and exerts its influence in giving rest to important organs of the body.

The main symptoms of sleep such as slowing of the heart, fall in blood pressure and diminished muscular activity therefore prompted Prof. W. R. Hess of Zurich to emphasize that 'sleep' also is a parasympathetic phenomenon 'comparable to the vagus control of the heart'. He pointed out that constriction of the pupils seen during sleep denotes an increase in the parasympathetic tone. Hess also drew attention to the work of Koch (1932) who found that an increase in the carotid sinus pressure of dogs just recovering from an anaesthetic led to an inhibitory state closely resembling sleep and the parasympathetic tone was simultaneously increased. Further, Hess injected drugs like ergotamine, which inhibit the sympathetic activity, into the 3rd ventricle of cats and succeeded in inducing typical sleep. Several experimental observations have since been reported supporting Hess's contention that the parasympathetic tone is increased during sleep. Samaan (1934) for example has shown that the bradycardia in dogs during sleep is due to augmentation of the vagal tone. Some clinical observations also lend support to this view. The value of ephedrine, a sympathomimetic drug, in the treatment of narcolepsy is now well established and shows

the parasympathetic nature of the attacks of sleep that occur in narcolepsy. Similarly, it is a well-recognized clinical observation that attacks of asthma frequently begin during sleep and asthma is more likely to occur when the parasympathetic tone is increased. There is, therefore, considerable experimental and clinical evidence to support the view put forward by Hess that sleep is a parasympathetic phenomenon.

If now we recall the most interesting work of Sir Henry Dale (1934) and his colleagues and a number of other workers showing the close relation between parasympathetic and acetylcholine, and if we admit that sleep is a parasympathetic phenomenon, we are at once confronted with the proposition 'Is acetylcholine the sleep producing hormone?'

Chemical theory of sleep

Before I put forward before you the experimental evidence which suggests that acetylcholine may act as the 'sleep hormone', I shall make a few remarks about the 'sleep centre' in the hypothalamus and the chemical theory of sleep. The existence of a 'sleep centre' in the region of the 3rd ventricle of the brain was suggested by Mauthner as early as 1890. Economo (1928) concluded from his vast clinical and pathological experience of lethargic encephalitis that the 'sleep centre' was situated in the region where the aqueduct of Sylvius opens into the 3rd ventricle. More recently Hess (1932) demonstrated that electrical stimulation of the diencephalon by specially constructed electrodes promptly produced sleep in cats. Recognition of the 'sleep centre' in the hypothalamus divided physiologists into two schools, holding two different views on the theory of sleep. Those who supported the 'cortical theory' were led by Pavlov (1927) who considered sleep to be a phase of internal inhibition. Pavlov based his arguments from his experiments on conditioned reflexes. He found that an acoustic stimulus, like ringing of a bell, followed by food established a conditioned reflex in dogs. When this reflex was established, just ringing of the bell produced salivation and increase of other digestive secretions, because the dog expected food immediately afterwards. If after establishment of this conditioned reflex the bell is rung but no food presented, the dog often falls asleep. Before the dog falls asleep, however, the flow of digestive secretions is stopped due to inhibition of cerebral centres controlling these secretions. According to Pavlov, this inhibition of localized centres in the cerebrum spreads over to the whole of the cortex and produces sleep. The other school who support the 'subcortical' theory recognize the existence of sleep centre in the hypothalamus and hold that the phenomenon of sleep is governed by this centre. A third school has also arisen who try to subscribe both to the cortical and subcortical theories.

I shall again refer to Pavlov's theory later. Apart from Pavlov's theory the only other theory which has a good experimental background is the 'chemical theory' of sleep first advocated by Pieron (1913). Pieron found that if the cerebrospinal fluid of dogs kept artificially awake for prolonged periods, is withdrawn and injected into the cerebral ventricles of normal dogs, such an injection produced as urgent a desire for sleep in normal dogs, as was manifested by dogs deprived of sleep. He therefore thought that the cerebrospinal fluid of dogs deprived of sleep contained a chemical substance having a hypnotic action and termed this substance 'hypnotoxin'. Pieron's theory was recently supported by the careful work of Schnedorf and Ivy (1939). Since Pieron's publication of his results several substances have been injected into the cerebrospinal fluid of experimental animals and as some of them produced a condition like sleep, claims made for them as 'sleep hormones'. I shall briefly refer to some of them.

Demole (1927) found a decrease in the blood calcium during sleep and thought that the calcium was taken up by the brain centres responsible for sleep. He therefore injected small quantities of calcium in the infundibular region of cats and succeeded in producing typical sleep. These observations were confirmed by Cloetta and Fischer (1930) and La Fora and Sang (1931). Bergren and Moberg (1929) found that mere insertion of needles in the infundibular region produced sleep in animals and previously Gollwitzer-Meir and Kroetz (1924) had failed to find any change in calcium concentration in blood during sleep.

Zondek and Bier (1932) working on the compounds of bromine, found that these are diminished in the Pituitary and increased in the medulla in artificial sleep and therefore postulated that sleep was due to the pouring of 'brome hormone' by the Pituitary gland.

Marinesco and his associates (1929) pointed out that choline injected intracerebrally produced sleep preceded by agitation and increased muscular activity.

Kroll (1933) found that extracts of the brain of sleeping animals, injected intracisternally in cats produced typical sleep. The original sleep was either produced by administration of drugs or was the result of hibernation.

Lastly, I (Dikshit, 1935) injected very small quantities of acetylcholine (in gammas) into the cerebral ventricles of cats and succeeded in producing a condition closely resembling sleep. These results were confirmed in dogs by Schnedorf and Ivy (1939) and to a certain extent in man also by Henderson and Wilson (1937).

It will thus be seen that quite a number of substances have been claimed to act as sleep producing 'hormones' because their direct application to the brain centre or centres produces a

condition resembling sleep. If a chemical substance is responsible for natural sleep, it should, besides its action on the sleep centre, satisfy several other conditions. Thus it must normally be present in the central nervous system, it must not be very stable and its action on the brain centres should be reversible. The presence of a special mechanism in the body to control the activity of this substance will be an additional point in its favour. Moreover, the pharmacological action of this substance on the central nervous system must agree with the physiological changes that are known to occur during sleep. The final proof must, however, rest with the actual demonstration of the fact that this substance accumulates around the sleep centre during sleep and disappears on waking.

If we look at the so-called 'sleep hormones' from these points of view we are at once faced with the fact that none of the substances I have mentioned above satisfies all the conditions. I, however, submit that acetylcholine has been shown to satisfy all of them except the last one. It has not yet been possible for me to put forward definite evidence to say that acetylcholine accumulates in the hypothalamus during sleep and disappears when the animal or subject awakes. I, however, feel that what I am going to say in the next few pages warrants the conclusion that acetylcholine deserves a careful consideration as a sleep producing 'hormone'. The rôle acetylcholine plays in mammalian physiology has been well recognized. We now know how it plays a very important part in the control of voluntary and several involuntary muscles and how it acts as a chemical mediator at the cholinergic nerve terminal. We have also got sufficient evidence to say that it is concerned in the synaptic transmission of the sympathetic ganglia. Is this ester equally concerned as the chemical mediator at the synapses of the central nervous system? The question is yet to be answered, but evidence is gradually accumulating to show that it is (Chang *et al.*, 1937). From this point of view alone the rôle acetylcholine plays in the regulation of the different functions of the central nervous system deserves a careful study.

Is acetylcholine a 'sleep producing hormone'?

I have mentioned above the conditions that a substance should fulfil before it could be accepted as a sleep producing 'hormone'. Let us examine how acetylcholine answers these conditions.

(i) *Action of acetylcholine on sleep centre:*

In a preliminary note read before the Physiological Society of Great Britain it was reported (Dikshit, 1935) that acetylcholine injected in very small quantities (less than 1γ) into the lateral ventricle or into the hypothalamic region of cats produced

a condition closely resembling sleep. These experiments were repeated further and the results mentioned above confirmed. It was also found that the response in different animals varied considerably and it also varied in the same animal. The typical phenomenon of sleep was observed in some animals while in others only drowsiness was evident. In a certain number of experiments drowsiness was preceded by excitation and this occurred more frequently with intraventricular than with hypothalamic injections. These experiments were repeated in dogs by Schnedorf and Ivy (1939). They found that dogs who received acetylcholine into the lateral ventricle passed into a condition closely resembling sleep, while those who received it into the cisterna magna showed only a depression. Henderson and Wilson (1937) repeated these experiments in man. They injected large quantities (up to 7·5 mg.) of acetylcholine intraventricularly in eight patients. The procedure slightly differed in these cases, but the observations were very carefully made and systematically recorded. They found that out of the eight cases who received acetylcholine intraventricularly one passed into profound sleep immediately after the injection, two showed drowsiness but not deep sleep and the remaining five cases no sign of sleep at all. In all these cases, however, nausea, vomiting and intestinal peristalsis were constant effects and so was sweating.

Injections of acetylcholine into the lateral ventricle will naturally affect all centres that line the ventricular system of the brain. A large number of centres will therefore be involved and the reactions will naturally be different from those which one would expect by application of the ester to a localized centre in the brain. The possibility of action on one group of centres nullifying the action on some other group would also exist. Thus the visceral reactions produced by acetylcholine may seriously interfere with the results of its reaction on the sleep centre. Nevertheless, all the experiments quoted above go to show that acetylcholine can produce sleep by its action on the sleep centre.

(ii) *Does acetylcholine exist normally in the brain?*

We are on a more firm experimental basis regarding the presence of acetylcholine in the brain. Since the observation of Schaffer and Moore (1896) that extracts of the brain produce a fall in blood pressure when injected intravenously, there has been a controversy about the nature of the depressor substance in the brain extracts. Some observers like Mott and Halliburton (1899) thought it was choline while others like Vincent and Sheen (1903) did not think it to be so. While working in Edinburgh, I attempted to see if acetylcholine was present in the brain or not and by employing some recent biological tests for acetylcholine was able to show (Dikshit, 1933, 1934*a*) that

it undoubtedly does exist in the brain tissue. Quantitative estimations of different portions of the brain showed that the concentration of acetylcholine was highest in the basal ganglia. Higher concentrations of this ester in the basal ganglia than other parts of the brain are significant when we take into consideration the recent claims, made with increasing insistence, that these ganglia are the seat of a number of visceral activities. These observations were later confirmed by Kwiatowski (1935) and also by Barsoum (1935). Since then a number of workers have not only found acetylcholine in the brain, but have also shown that slices of brain tissue can actually form acetylcholine *in vitro* (Quastel *et al.*, 1936; Stedman and Stedman, 1937; Mahal and Dikshit, 1937; Dikshit, 1938). More recently, Chute, Feldberg and Smyth (1940) have shown acetylcholine formation by the brain in perfusion experiments. One can, therefore, say with certainty that not only is acetylcholine present in the brain but it is formed there continuously.

(iii) *Is there a special mechanism in the body to control the action of acetylcholine ?*

Dale as early as 1914 suggested the possibility of an esterase in the body which would destroy acetylcholine. Several workers since then (Engelhardt and Loewi, 1930; Matthes, 1930) have confirmed this observation. Dr. E. Stedman of Edinburgh and his associates (1932) later discovered an enzyme in the blood which has the specific action of destroying esters of choline and they named this enzyme 'choline-esterase'. A number of contributions by Stedman and his associates and also other workers (Gaddum, 1936) have since then established the rôle that choline-esterase plays in controlling the activity of acetylcholine in the body. It is significant to note that Stedman and Stedman (1936) failed to find any choline-esterase in the cerebrospinal fluid, but found it in large quantities in the brain tissue. Further, they made the important observation that the amount of this enzyme in the basal ganglia was about twice that present in the cortex. We have, therefore, unassailable evidence to show that there exists in the body tissues a mechanism which controls the activity of acetylcholine and that this mechanism—the choline-esterase—is present in the brain and especially in that part of the brain where the sleep centre is situated.

(iv) *Does the pharmacological action of acetylcholine on the brain centres agree with the physiological changes seen during sleep ?*

Earlier I have referred to only four changes that occur physiologically during sleep, changes concerning circulation, respiration, muscular movements and sweat secretion. Action of acetylcholine on brain centres is usually studied by introduction

of the drug into the ventricular fluid of the brain. Such introduction produces action on several centres lining the ventricular system and therefore, as discussed above, information so obtained may be misleading. Moreover, such actions will depend upon the dosage employed and upon the concentration of choline-esterase present in the parts of the brain concerned with these actions. However, it may be stated that as far as the circulation, respiration, muscular movements and sweat secretions are concerned, the action of intraventricular acetylcholine agrees with the changes seen during sleep. I investigated the action of acetylcholine on circulation and respiration (Dikshit, 1934*a*) by injecting small quantities of the drug into the lateral ventricles of cats and found that respiration was definitely depressed and the blood pressure was very slightly lowered by such injections. Depression of respiration and lowering of blood pressure in sleep have already been discussed. Further, I pointed out (Dikshit, 1934*b*) that application of acetylcholine to the brain centres can produce an irregularity of the heart. It is true that every individual does not get an irregular action of the heart just before falling asleep, but in those who are susceptible to such irregularities, it is a common clinical experience that the irregularities are increased at the onset of sleep.

As regards muscular movements, the marked diminution in movements of voluntary muscles by central application of acetylcholine can be demonstrated in animals who are just recovering from a volatile anaesthetic. Under deep ether anaesthesia, a trephine hole is made in the skull of a cat to introduce acetylcholine into the ventricles. The muscular movements are registered graphically by placing two large balloons partially filled with water on two sides of the animal and connecting both to a recording tambour. The anaesthetic is then lightened and as the animal comes into the first stage of anaesthesia it begins to struggle and these movements are registered on a moving kymograph. A small quantity of acetylcholine (1 or 2γ) is then introduced into the lateral ventricle through the trephine hole and the effect of the injection is seen immediately afterwards. The struggling movements become less and less and sometimes they are completely abolished for a short time. In experiments described previously, introduction of acetylcholine into the cerebral ventricle of unanaesthetized cats led to a condition resembling sleep and thus was associated with lessened muscular tone and movements. Therefore, action of acetylcholine on voluntary muscular movements is similar to the action seen physiologically during sleep.

Secretion of sweat is difficult to demonstrate in the experimental animals. Cats have a few sweat glands on the foot pads, but it is difficult to demonstrate increase in secretion of these glands. In their experiments on hospital patients, however, Henderson and Wilson (1937) found sweating to be almost

uniformly associated with intraventricular acetylcholine injection. According to these authors sweating accompanied nausea but was present in some cases to a degree which was much more than could be found in nausea alone and in others it was profuse. Sweating after sleeping is a common observation when environmental conditions are suitable for sweating. Such conditions are naturally present more often in the tropics than in colder climates.

It will thus be seen that the pharmacological action of acetylcholine on the brain centres and the physiological changes seen during sleep agree at least on those points which I have just discussed. There is one important discrepancy, however, which was noted by Schnedorf and Ivy (1939) in their experiments on dogs. They observed that intraventricular injections of acetylcholine produced sleep in dogs but the rectal temperature was simultaneously raised. Rise in temperature is not a phenomenon observed in natural sleep and therefore Schnedorf and Ivy (1939) were inclined to believe that the response to acetylcholine was not truly physiologic. Henderson and Wilson (1937) on the other hand found a drop in body temperature after intraventricular acetylcholine injections, but they were working with human subjects who responded with perspiration to acetylcholine and perhaps this sweating helped to lower the temperature. Dogs cannot perspire and therefore Schnedorf and Ivy could not notice a fall in temperature. It is interesting to note in this connection, however, that Shiziraku (1925) kept dogs artificially awake for prolonged periods and when their desire for sleep was extreme a rise in their body temperature was noted.

Temperature regulation is governed by a special centre in the hypothalamus and it is not possible to say whether the fall in temperature during natural sleep is due to the action of the 'sleep hormone' on this centre or due to vascular changes and diminished motor activity. I shall, however, again take the liberty to repeat what I have said before that intraventricular injections of acetylcholine produce a much more diffused action on the brain centres than local liberation of the ester in certain localized parts of the brain would do.

(v) *Is there accumulation of acetylcholine in the sleep centre during sleep?*

We now come to the crucial test of this 'sleep hormone' theory, viz., demonstration of accumulation of acetylcholine in the sleep centre during sleep. I must state in the beginning that all my attempts to get this proof have failed so far. The problem is associated with a number of technical difficulties. Acetylcholine is very rapidly destroyed by the enzyme, choline-esterase, and any experimental procedure in a sleeping animal

disturbs it and leads to the waking state. I therefore decided to tackle this problem indirectly and shall describe very briefly the nature of experimental procedures I have adopted.

(a) Relation between choline-esterase in blood and acetylcholine concentration in the brain :

In a paper read before the Indian Science Congress (Dikshit, 1937), I had mentioned that there is a direct relationship between the acetylcholine concentration in the brain and choline-esterase content of the blood. These experiments were made on different species of animals and it was found that whenever there was a high concentration of acetylcholine in the brain, there was also a high concentration of the enzyme in the blood. This relationship was noticed by Dr. Stedman, F.R.S., of Edinburgh some years previously. It was therefore thought that examination of the blood of a subject might give an idea about the acetylcholine concentration in his brain. We therefore examined the blood of several volunteers at noon and at midnight with a hope of finding a difference in the choline-esterase content of the two samples of blood but failed to find any such difference whatsoever. Further, Dr. Mahal (1938) working in my laboratory in Bombay examined the blood of guinea-pigs which were kept artificially awake for several days and found no difference between the choline-esterase concentration of the blood of these animals taken before and after prolonged sleeplessness.

(b) Appearance of acetylcholine into the cerebrospinal fluid of animals deprived of sleep :

I kept cats artificially awake for several days and examined their cerebrospinal fluid to see if any acetylcholine could be detected in it. The cats were deprived of sleep by putting them in a slowly revolving cage. In such experiments the animals have to move all through 24 hours and the experiments are complicated by a third factor of muscular fatigue. However, I failed to see any appearance of acetylcholine in the cerebrospinal fluid of these animals after prolonged wakefulness. Schnedorf and Ivy (1939) made more careful experiments with dogs and also failed to find any acetylcholine in the cerebrospinal fluid of dogs deprived of sleep. The idea in these experiments was that if acetylcholine accumulates in large quantities around the sleep centre it may partly escape into the cerebrospinal fluid and its presence in this fluid could be detected by employing sensitive biological tests. Normal cerebrospinal fluid contains no acetylcholine and no enzyme. The enzyme which is present in the brain tissue however appears to destroy acetylcholine completely and not the slightest trace of the ester appears in the cerebrospinal fluid.

(c) Estimation of acetylcholine in the basal ganglia of animals deprived of sleep:

These experiments were made on guinea-pigs and rats. The animals were kept awake by putting them in a revolving cage and therefore the factor of fatigue was present in these experiments also. After five days of sleeplessness when the guinea-pigs were taken out of the cage they exhibited the most urgent desire for sleep. Such animals were killed immediately after removing from the cage and the acetylcholine content of the basal ganglia estimated and compared with that of normal animals. In the beginning I got the impression that I was finding more acetylcholine in the basal ganglia of sleepless animals as compared with normal ones, but the individual variations were found to be far too wide to arrive at any definite conclusion. Similar results were obtained with rats also. I feel that this procedure may give some information if a very large number of animals is used and the results studied statistically.

(d) Effect of Physostigmine:

The action of physostigmine, an alkaloid obtained from the calabar bean, in preventing the hydrolysis of acetylcholine by the specific enzyme is now well established. Hydrolysis of acetylcholine by the enzyme in the brain could therefore be prevented by administration of this drug and if this drug could be administered in sufficient quantities to neutralize the enzyme action, sufficient accumulation of acetylcholine could occur in the brain to produce its central effects. Unfortunately, however, the drug is far too toxic to permit of its administration in adequate doses. Besides, the side actions of such administration are far too powerful to enable the phenomenon of sleep to be studied. It is interesting to note, however, that the central depressant action of physostigmine has been recognized and Sollmann (1933) mentions that this depressant effect has been made use of clinically in diseases like epilepsy though without much success. Mention must, however, be made of the experiments of Dost (1934) in this connection. To test Hess's theory of sleep Dost injected a large number of drugs intramuscularly in cannaries, physostigmine being one of them; and he found injections of physostigmine produced sleep in these birds. Further, one of my colleagues working in the Royal Infirmary of Edinburgh gave Miotin, a compound prepared by Stedman which has identical action as that of physostigmine, to a patient and found that after the preliminary visceral effects had passed off the patient fell into deep sleep. Physicians and surgeons have, these days, many opportunities of using prostigmine or physostigmine in their clinical work and if observations are made with special reference to sleep, I think such

clinical data will materially help to verify the theory of sleep I have postulated.

However, to come back to the effect of physostigmine in animals, I gave this drug hypodermically to cats, dogs, and monkeys. As explained above, the visceral effects of such injections were far too severe to allow the phenomenon of sleep to be observed properly, but after these effects wore off, a definite drowsiness was observed in some of these animals.

Discussion

The remarkable experimental work of Pavlov (1927) on conditioned reflexes has shown that sleep is due to spread of internal inhibition. I have already referred to Pavlov's work and explained that Pavlov holds the cortex entirely responsible for sleep. Goltz (1892) on the other hand has shown that decorticated dogs can sleep and this observation was confirmed by others (Rothman, 1923; Rademaker and Winkler, 1928). If dogs without cortex can sleep, Pavlov's hypothesis cannot be entirely correct. Criticism has also been levelled against Pavlov's experiments. Kleitman (1929) observed that in some experiments on activity of gastro-intestinal tract made in his laboratory he had to use stands similar to those used by Pavlov and he often noticed dogs sleeping, though no conditioned reflexes were involved. He also mentions a case in which a dog continued actively secreting saliva though asleep and inhibition of salivary secretion followed and did not precede onset of sleep.

If sleep is a conditioned reflex, it is not possible to understand how a new-born baby can sleep from the moment it is born. The diurnal variation in sleep and activity of monophasic animals could be understood on the conditioned reflex theory, but not the sleep of polyphasic animals who have sixteen periods of rest and activity during 24 hours. Another important question is, does the sleep of lower forms of vertebrates, for example that of frogs or fish, depend on conditioned reflexes or is their sleep different altogether from the sleep of higher vertebrates?

It is, however, not possible to deny that conditioned reflexes play an important part in the diurnal periodicity of sleep, at any rate sleep of higher animals. We are accustomed to sleep under certain conditions and any trivial change in these conditions, such as an uncomfortable bed or a different bed room may be sufficient to prevent sleep. The diurnal periodicity of sleep in man is more a habit than a physiological necessity and is therefore, as Pavlov says, dependent on the cortex.

Sleep as a physiological necessity is, however, a different proposition altogether. In a normal individual an uncomfortable bed causes sleeplessness for a night or two, but there will always be a limit to this sleeplessness. The necessity of sleep after

prolonged wakefulness is so urgent that a person can sleep in most adverse conditions. Instances have been mentioned during the Great War when people riding or marching were actually sleeping. Animals deprived of sleep for long periods can sleep in most unusual positions. In such instances conditioned reflexes could play but little or no part; sleep as a physiological necessity therefore cannot be said to be under the influence of the cerebral cortex and the function must be relegated to sub-cortical centres. I have already referred to the evidence which has accumulated in support of the existence of a sleep centre in the hypothalamic region. The experimental evidence I have put before you is based on recognition of this sleep centre. How is this sleep centre activated? This is the question for which an answer is sought and I have presented to you some facts which tend to show that acetylcholine could be considered as an agent which can lay some claims as a sleep producing 'hormone' which activates the sleep centre. I frankly admit that the evidence I have presented is more indirect than direct. It has not been possible to demonstrate actual accumulation of acetylcholine in the sleep centre during sleep. Attempts to demonstrate it in the cerebrospinal fluid of animals deprived of sleep have failed in the hands of others as in my hands. My attempts to show its increased concentration in the basal ganglia after prolonged sleeplessness have given equivocal results. Indirect approach to the problem by estimation of blood choline-esterase have given no indication.

On the other hand, the indirect evidence is not very meagre. The importance of acetylcholine in physiology coupled with Hess's contention that sleep is a parasympathetic phenomenon and Dale's contribution explaining the rôle acetylcholine plays in parasympathetic phenomena gives a clear ground to work upon. Existence of acetylcholine in the brain, its higher concentration in the basal ganglia, and the presence of a special mechanism to regulate the activity of acetylcholine are important data supporting the view. Agreement between acetylcholine action on some brain centres and the effects of sleep on these centres also is in favour of acetylcholine being a 'sleep hormone'.

I am fully aware of the fact that I have discussed the problem of sleep from a very restricted point of view. I have not made reference to many other approaches to the subject like the recent researches on the brain potentials during sleep. I have also refrained from discussing other theories of sleep, because such a discussion would have been outside the scope of this address. There are many other points which will have to be investigated before the theory I have put before you is finally accepted. If acetylcholine is responsible for sleep, is there any other hormone which brings on awakening? Is the sleep of higher vertebrates and lower ones, like frogs and fish, similar?

What is the nature of the sleep of lower forms of life like earthworms? Do they sleep at all? Do plants sleep? Is there any disturbance in the acetylcholine metabolism of the central nervous system in certain psychopathies or mental disorders? These and similar questions will naturally arise and it is my earnest hope that attempts will be made to answer them by further experimental and clinical research.

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SECTION OF PSYCHOLOGY AND EDUCATIONAL SCIENCE

President :—I. LATIF, M.A., PH.D.

Presidential Address

(*Delivered on Jan. 7, 1941*)

PSYCHOLOGY AND THE FUTURE OF MANKIND

I

The history of the civilized world presents a sad record of the repeated failures of human society to ensure the sanity and stability of mankind. Thousands of years have passed since man forsook his savage haunts and modes of living, and entered the domain of civilization with high hopes and expectations for a brighter destiny—only to find himself involved in far more serious perils. Not only does he find himself in greater perils to his physical safety from the antagonistic assaults of his fellow-creatures, but he is also constantly exposed to graver dangers to his sanity from the various factors inherent in the very nature of civilization. The perils to his physical safety have been tremendously increased by the use of scientific instruments of human destruction. Man's control of the instruments for destroying his fellow-creatures has reached such a remarkable degree of perfection, that the very existence of the human species appears to be seriously jeopardized. The dangers to his sanity have become increasingly threatening with the irrational control which civilized society has come to exercise over his fundamental natural urges. This latter danger is so fatal to the health, sanity and efficiency of the individual, that it appears that this civilization, in whose friendly support man had placed his implicit confidence, is likely to prove his most dangerous foe. His supposed safety and stability within civilized society is now being exposed as an illusion and the destiny of the human race is becoming increasingly dark and uncertain. Even the belief that there has been a steady progress of reason during the history of the human race is now fast vanishing.

The usual arguments of the protagonist of modern civilization concerning the manifold advantages of the scientific research of their times, as a rule, leaves out of account the fact that the scientific achievements of our age have gone beyond man's ability rationally to control them. Consider, for instance,

how the modern devices for the intercommunication of news and thought, which were expected to unite human family closer together in greater understanding and tolerance, have served to aggravate the traditional hostility and national arrogance of men. And when we think of the ways in which the fruits of the scientific labours of man have been used for the destruction of mankind, the conviction grows on us that these are by no means the 'unqualified enrichment' of human life that some people claim them to be.

The uncertainty concerning the future of the human race which distresses the student of civilized society today is the logical result of the general discredit into which the redemptive efforts of many generations of civilized mankind have now fallen. Each generation in turn takes up the task of redressing human society with high expectations—only to find humanity involved in a progressively worse plight. Every day brings to light evidence of the antagonism, hatred, competition, indifference and hostility which continually complicate social and international relations. To take only one instance, consider the ever-recurring international conflicts in Europe in spite of continuous efforts to ensure a peaceful settlement. Within the last one hundred years European history records the Boer War, the Franco-Prussian War, the War between Germany and Austria, the War between Prussia and Denmark, the Franco-Sardinian War against Austria, the Crimean War, the British Opium War, British actions in Africa, China, Palestine and elsewhere; French actions in Africa and Mexico and a host of other such conflicts down to the present war. What strikes the student of human nature is not so much the actual event of war as the constancy with which it repeats itself in spite of all the conscious endeavours of mankind to ensure a rational and peaceful state. The last world war, for instance, exhausted the strength and national resources of all the countries involved; and yet the survivors so far from disarming started arming again feverishly. Thus after four years of ruthless slaughter, and after world-wide conferences to ensure a sane and peaceful human society, Europe remained an armed camp—preparing for new wars and conquests.

A study of the available records concerning the sanity of man in civilized society reveals appalling facts and figures. The number of the victims of psychogenic disorders is definitely on the increase. These disorders are ultimately due to man's lack of emotional adjustment to the rigid demands of his cultural environments; they include neurasthenia, hysteria, anxiety-neuroses, phobias, obsessions and so forth. A large number of mild cases belonging to this classification still go unrecognized under the false diagnosis of anaemia, insomnia, gastric catarrh, debility, etc., rendering the therapeutic endeavours of orthodox medical systems futile. During the brief space of three years

24,000 suicides or attempted suicides were entered in the Archives of the Board for the Prevention of Suicides in Budapest. According to the report of one leading medical investigator, this city holds the world record for attempted suicides. The records of the United States of America show 150,000 suicides annually. Many other similar records might be quoted to show the extent to which the neurotic illness infests civilized society today. The case-histories of psychological clinics in any civilized city could yield additional evidence of the actual increase of neurotic disorders, domestic and marital disruptions and maladjustments.

Nor do the records of antisocial behaviour relieve the dismal perspective. The subtle and ingenious forms in which crime is progressively thriving in our modern society and the heavy toll it lays on our economic resources provide further evidence which destroys the individual's belief in the ability of civilization to satisfy all the rational demands of its members. The various forms of delinquency are so manifestly a repudiation of social conventions and taboos that we are forced to conclude that civilization does not satisfy all the demands of human personality, and in consequence a large number of its members are provoked to fly in the face of its laws.

We repeat that the great tragedy which attends the march of human affairs does not consist so much in these events which blight the history of the human race, as in the vicious circle in which mankind appears to be inextricably involved, so that mental disorders, crimes, political unrest, wars and unhappiness dog its steps at every turn.

II

But the most pathetic aspect of the situation is the profound ignorance of the leading intellectuals concerning the real causes of the manifold disorders with which mankind is afflicted. Consequently, little or nothing has been done to alter this situation. For, it must be adequately diagnosed before it can be remedied.

This seems to be an extraordinary instance of gross ignorance in an 'age of scientific enlightenment'. For, not only are we struck by the paucity of literature offering an adequate explanation of the causes which have conspired to bring about this situation but we find that the alleged explanations of a majority of those who have attempted to study this particular subject leave us, in the end, confused and mystified. Most of these tend to confuse the various issues involved in the situation. Moreover, they almost invariably suffer from a fundamental error which consists either in entirely ignoring the influence of the human factor in the aetiology of the present social disorders or conceding to it only a secondary and casual importance. In this way the root cause of the trouble is almost invariably

miscalculated. Irrelevant factors are frequently exalted into all-sufficient causes; and grandiloquent attempts are made to convince individuals that it is through the control of these causes that the final redress of human wrongs will be effected. Meanwhile little or nothing is done to explore the mental dynamics of the *homo sapiens* in a scientifically objective manner in order to discover the underlying causes at work. Thus having omitted or miscalculated the importance of the human factor, such studies are inevitably superficial, even when they are not wholly irrelevant.

Recent psychological enquiries into the individual and social behaviour of man are making it increasingly clear that apart from the scientifically objective study of the mental dynamics of the human behaviour it is not possible to understand adequately and remedy effectively the present trouble so as to ensure the sanity and stability of the human race. Without the help of psychopathological insight and technique, the situation will for ever remain an inextricable mystery and a constant menace to mankind. In the words of Samuel D. Schmalhausen: 'Whatever field of life we touch, straightway we are in the presence of problems of maladjustment. Whether we go over the field of criminology, juvenile delinquency, marriage and divorce, business relations, the institutions of the home, the church, the state, the school, or study the intricate taboos and sacred sanctions of ethical codes or peer into the mob-intricacies of journalism, or specialize in the phenomena of crowd behaviour, persistently and inseparably we are in the perturbing presence of problems that can only be approached intelligently from a psychiatric point of view. History, penetratingly conceived, is a branch of psychoanalytic psychiatry.' [1]

Of the several factors which have conspired to obscure the importance of the knowledge and application of the findings of psychological research in the scientific study of human affairs, we shall mention only a few here. In the first place, the extraordinary progress of the physical sciences has naturally led to the obscuring of the value of psychological science and the relegation of the mental determinants of human behaviour into the background. Man's discovery of physical laws and the utilization of the knowledge which enables him to deal with forces as they are manifested in the external world has outstripped his knowledge of the dynamic determinants of his behaviour. He is obsessed with the thought that since the knowledge of the laws of his physical environment have given him control over the world, the same laws will ensure his control over his own destiny. Consequently, an explanation of behaviour in terms of mental dynamics is relatively neglected. This physical bias characterizes the mental outlook of a majority of our leading scientists. Some

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[1] *Why We Misbehave*, pp. 71-72.

of them even go to the length of regarding a psychological approach as wholly irrelevant to any serious scientific endeavour at explaining and controlling the trend of human affairs. They even question the right of psychology to the status of a science. Very often the presence of a psychologist at a congress of scientists is regarded by them as anomalous if not altogether unwelcome. It is the physical scientist who truly represents the cause of science. The psychologist is a scientist only by courtesy. It is but natural that this indifference to the science of human psychology should darken counsel and render a majority of the explanations of physical speculators only partial endeavours at best.

In order to illustrate how indifference to psychological facts may distort one's explanation of human behaviour, we may take an instance from the speculations of those who claim to explain human activity exclusively in terms of economic laws. They treat of wealth as entirely independent of the laws of human psychology. Of course there is now a growing tendency to make a passing reference to the psychological aspect of economic transactions in the opening chapter of the text-books on the subject. But the casual and superficial character of these references often makes one wonder whether this is not merely an attempt to impress the reading public with the idea that psychological aspects of the science, if any, have been taken account of. The fundamental economic problems continue to be treated with the usual indifference to the laws of human psychology. The rise and fall of prices, the supply, demand and consumption of commodities are treated as if they were governed by laws outside the field of human psychology. Ignorant of, and indifferent to, the fundamental relation of the laws of human psychology to this field of human activity, economic speculators have repeatedly landed multitudes of credulous individuals in disastrous crises. But when we consider some of the solutions proposed by economic enthusiasts for the problems of social disorder, the superficial character of such explanations when unaided by the knowledge of human psychology, becomes even more obvious. For example, it has been a current belief in Soviet Russia that the only way to eradicate the criminal tendencies of an individual is the liquidation of economic inequality. Equal economic opportunities, it is claimed, will in the end result in the gratification of human needs so that no one will desire to prey upon the economic resources of society by antisocial methods. We freely concede that removal of unequal opportunities for earning wealth does in certain cases prevent antisocial behaviour. Our main objection to this claim, however, is that quite a high proportion of adult delinquents do not begin their criminal career on experiencing economic strain. Kleptomania, for instance, may find expression in the behaviour of well-to-do individuals.

Psychoanalytic research has shown that very often a conscious economic want may be only a disguised and repressed erotic wish. In a fairly large number of cases wealth or money has been discovered to possess this erotic significance. Not until this aspect of the overt human activity is scientifically explored can one assert with any degree of scientific certitude whether or not a specific instance of individual conduct, which to all appearances is the product of economic conditions, is really independent of deeper psychological motives. Not until this has been duly taken into consideration can we expect to have a scientifically complete explanation of the specific behaviour in question. 'However great our faith in the environmental determinants of human behaviour, in the truly astonishing power of economic and social forces to shape and mis-shape our lives, we shall be missing an amazing amount of insight if we ignore or minimize the importance of the human nature factors such as the psychoanalysts and the dynamic psychopathologists deal with .... There is a lurid chapter in the history of human conduct that has very little to do with specific economic determinants but has a great deal to do with certain distortions and perversions resident in human nature.' [1]

This brief discussion of the economic motive of human conduct will help us to understand how indifference to the laws of human psychology can obscure the true nature of the causes which are responsible for the present social disorders; and how ignorance of these causes renders the hope of their redress lamentably remote.

It has often been alleged that the relative youth of the science of psychology is responsible for the indifference with which its findings are treated. But when we consider the amazing progress which this science has achieved within the few decades of its career, we shall be obliged to look for a deeper reason. Its youthfulness would still leave the possibility of making use of the existing psychological knowledge open to a large majority of thinkers in the field of the social sciences. But it is not only the general indifference of leading thinkers but often their positive hostility to the science of psychology which requires a scientific explanation. Barring those provocative examples of certain philosophizing psychologists and the sterile stunts of 'brass-instrument' psychologizing enthusiasts, which may have brought discredit to this science, we shall find that this indifference and hostility to psychology can be traced, in the last analysis, to the great unwillingness of man to face himself. It appears that a large majority of the opponents of psychology are people who by the rigid restraints of modern culture are unable to encounter calmly the contents of their own mental make-up. Their indifference to this science is, to

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[1] Schmalhausen: *op. cit.*, p. 73.

a large extent, a defence mechanism against the possibility of the revelation of certain mental dynamics which are, so to speak, looked upon as contrabands within the social environment of modern culture. This ostrich-like attitude serves as a narcotic to lull them into a self-complacent slumber. What these mental contrabands really are we shall explain presently. Meanwhile it may help us to understand their provocative character if we remember that the history of modern culture records innumerable instances in which the flood of social disapproval and hostility has been directed against any objective study of human nature which may throw light on certain instinctual demands which have been tabooed by the conventions of civilization. With his extraordinary insight into this fact Sigmund Freud has clearly demonstrated how human beings can ill-afford to endure any shock to their narcissistic self-complacency and that contempt for any scientific technique which bids fair to ensure self-knowledge to the individual is very often used as the principal weapon of the resistance. This resistance incidently is a measure of the mental health of modern society. For a society which does not have the courage to examine its own motives must be basically sick.

III

Let us consider for a moment what may be the contents of this self-knowledge so that we may be able to understand why civilized man should invariably build up such a strong resistance against it. But we must first disabuse our minds of the popular belief that the mental structure of the civilized individual is fundamentally different from that of his savage ancestors. This prejudice has largely obstructed an objective study of the determinants of human behaviour, and not until we discarded it shall we be in a position to observe the contents of the human mind in their true nature and setting. The vast and varied data now available in the field of psychoanalytic research clearly indicate that fundamentally the same mental dynamics which motivated the behaviour of his savage ancestors thousands of years ago, still, under the gloss of modern culture, continue to determine the conduct of modern civilized man. Whatever the cultural standards of his society, under the influence of a strong emotional experience or of a threat to his personal interest, man's primitive impulses break through his cultural restraint. 'Any emotional stress, a sudden panic, a threat of calamity, a failure in business or in marriage, a severe illness, the death of a loved one, and it is liable to stampede man into conduct prejudicial to himself and to his neighbours. It may even bring about his own destruction.' [1] Such observations clearly show that behind man's

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[1] Glover, E.: *The Dangers of Being Human*, p. 49.

facade of rational conduct there exists a primitive mental structure which regulates his individual and social life.

By the primitive mental processes we mean such motives to conduct as animistic beliefs, totemistic taboos, and a thousand forms of hostilities, fears and irrationalities. A large number of these are subtly disguised in modern culture so as to elude recognition without the aid of a special psychological technique. Thanks to the mechanisms of repression and displacement they flourish undetected by the victim. The notion that modern man has evolved beyond the mental stage of his savage ancestors keeps him in the dark with regard to their existence within his mental structure and thus less vigilant against their destructive power. This is the chief danger of modern civilization. It harbours within itself mental mechanisms of extreme destructive potency and it is incapable of defending itself against them because it is unconscious of their very existence. And yet without recognizing their existence, one would be wholly at a loss to account for the 'inhuman atrocities', the hatreds, hostilities, and wars, the savage superstitions, the neurotic disorders and psychotic manifestations of the individual which flourish unabated today even in the most 'advanced' civilized societies. The dismal catalogue of 'hallucinations, obsessions, delusions, paranoid trends, moods running the whole gamut of manic-depressive psychoses, psychoneurotic tensions and unstabilities, organic and functional inferiorities, phobias, hysterical outbreaks, tendencies to melancholia, sexual perversions, narcissistic attitudes, egoistic indulgences, exhibitionism, insane ambitiousness, anxiety, compulsions, habit neurosis, automatism in behaviour' is the logical result of the clash of primitive impulses with the conventions of civilization. This alone can account for the hostile character of the international relations today, which can clearly be traced to these savage mental processes which continue to operate under the civilized gloss of the present day culture. Theoretically international problems should call for rational remedies. But how rarely in the history of civilized society have people found it possible to wait long enough for a rational redress of wrongs. Under provocation, the inflammable savage impulses of our nature burst forth into terrible conflagration. Modern man has not been able to shake off the influence of the primitive processes which existed in the darkest phases of human development.

The failure of civilized society to put an end to warfare illustrates the impossibility of ensuring peaceful settlement so long as its members do not clearly realize the existence of the forces in their personality which invariably bring about war. The main trouble with the efforts to put an end to the war is that they have been directed against wrong objectives. For instance, they have been based upon the assumption that disarmament of an opponent is the only effective method of putting

an end to war. The idea is not at all new, and is only a slight variant of an ancient maxim that 'to despoil our neighbours deprives them of the means to injure us.' Accordingly the repeated failures of peace organizations to stop war have been attributed to the incomplete disarmament of hostile nations rather than to the failure of political leaders to intelligently understand and rationally control the determinants of human behaviour whose operation invariably issues in war. The possession of destructive weapons is only a secondary consideration. Mental determinants are the primary causal factors. So long as the basic motives of war are not psychologically diagnosed and controlled, mere legislation on the control of armaments cannot eradicate war. The control of armament will only limit the extent of destruction; it cannot eradicate aggression, hostility, fear, competition, megalomania which invariably produce war. A clear and objective understanding of the significance of these urges is the first step towards preventing war. Without this essential step peace organizations, international conferences and treaties and diplomatic negotiations are entirely powerless to stop war.

But here again it is the misfortune of civilized man that he fondly hugs the illusion that he is beyond the influence of the motives which provoked his savage ancestor to warfare. Owing to the mechanism of repression, if he should by any chance attempt to look for the causes of human warfare within his own nature, the result would be negative. Consequently, he explains war in such a way as not to hurt his sense of self-complacency. He projects his own primitive motives upon his opponent whom he regards as a savage or a lunatic, and whom he deems it a moral obligation to resist. It is obvious how the conventions of civilized society invariably regulate the specific pattern of the behaviour of modern belligerents. It is not a pure accident that each of the combatants unconsciously realizes the need of rationalizing his motives for war by convincing himself, and very often others of his party, that he is fighting for a righteous cause and not for any form of self-interest. How often in the history of civilized society has man unconsciously or otherwise attempted to exonerate himself for indulging in savage human destruction by labelling it a 'holy war'. War in savage societies was not so subtly disguised.

But though the motives of warfare were more or less clear to the savage, they were not any the less dangerous. All wars, whether waged by civilized or primitive groups, threaten the stability of the human race and the peace of human society. But with the undisguised knowledge of the motives, the savage was in a better position to control the event of war, at least on theoretical grounds, when he so desired. But curiously enough, none of the civilized organizations which aim at the prevention of war have ever spent a single penny for a scientific investigation

and control of the mental conditions which produce war. Only when the nations are able to perceive these mental forces and recognize their real nature in a frank and fearless manner, will it be possible to prevent war through the emotional re-education of its members.

It may be contended that though true of certain individuals under strongly provocative circumstances and peculiar mental outlook, our statement of the operation of the savage processes in the life of the normal civilized man is a gross exaggeration. But the objective study of the so-called normal individual of our age, does not offer any different perspective. Few of us spend more than a few hours during the entire day in a completely rational state of mind. And when the rigid demands of our social and professional life leave us to ourselves for a moment, we naturally tend to relapse into modes of behaviour which under analytic examination are clearly primitive and irrational. Two lines of evidence may be advanced to confirm the truth of this statement: (*a*) the psychopathological study of the adult individual behaviour; (*b*) the genetic study of the mental life of the individual. Both of these lines of evidence converge on the truth of the statement that the mental processes of the modern man, in spite of the cultural demands of his society, are inherently and basically primitive. The infant, in the modern society, before the code of modern civilization influences his conscious behaviour, undisguisedly manifests the same hostilities, rivalries and irrational fears which find devious and disguised expressions in the behaviour of the adult within his cultural environment. The psychoanalytic study of the dreams of apparently normal individuals clearly brings out the savage character of their dominant wishes and desires.

IV

When we set out to inquire how it is that the savage elements of our nature remain generally unrecognized in our conscious mind, we are naturally led to the consideration of certain psychological devices to which references has already been made. The mechanism of 'repression'—a process through which an impulse which comes into conflict with a strong cultural demand is driven into the unconscious—is obviously at work here. This process is further aided by another unconscious mechanism called projection through which the individual unconsciously responds to the conflicting urge by an effort to deny its existence within himself and by attributing it to an external object. The latter, to some extent, accounts for the extraordinary conviction with which certain paranoics attribute guilty motives to their neighbours. This also to a very large extent explains the abnormal zeal of the religious fanatic or the hypercritical prude. The more violent their condemnation of others, the

stronger their repudiation and fear of these impulses within their own lives. 'The real motives of the reformer,' says Hendrick, 'who consciously believes he is protecting others' morality and unconsciously enjoys a mass of obscene literature in the rôle of public censor are commoly recognized.'

The intensity of repression depends upon the extent to which conventional ethics has been allowed to impose upon the human individual an ideal of conduct in total disregard of the instinctual demands of his nature. Renunciation of instinctual urges is the fundamental requirement of conventional morality. In obedience to this man's aggressive, vindictive, and erotic urges have in the course of civilized culture been blindly subjected to a progressive process of repression. 'Civilization,' says Sigmund Freud, 'is the fruit of renunciation of instinctual satisfaction, and from each new comer in turn exacts the same renunciation.'[1] He goes on to describe the various psychological moments of the process so clearly that we shall quote his own words: 'Civilized society, which exacts good conduct and does not trouble itself about the impulses underlying it, has thus won over to obedience a great many people who are not thereby following the dictates of their own natures. Encouraged by this success, society has suffered itself to be led into straining the moral standard to the highest possible point, and thus it has forced its members into a yet greater estrangement from their instinctual dispositions. They are consequently subjected to an unceasing suppression of instinct, the resulting strain of which betrays itself in the most remarkable phenomena of reaction and compensation formations. In the domain of sexuality, where such suppression is most difficult to enforce, the result is seen in the reaction-phenomena of neurotic disorders. Elsewhere the pressure of civilization brings in its train no pathological results, but is shown in malformations of character; and in the perpetual readiness of the inhibited instincts to break through to gratification at any suitable opportunity. Anyone thus compelled to act continually in the sense of precepts which are not the expression of instinctual inclinations, is living, psychologically speaking, beyond his means, and might objectively be designated a hypocrite, whether this difference be clearly known to him or not. It is undeniable that our contemporary civilization is extraordinarily favourable to the production of this form of hypocrisy. One might venture to say that it is based upon such hypocrisy, and that it would have to submit to far-reaching modifications if people were to understand to live in accordance with the psychological truth. Thus there are very many more hypocrites than truly civilized persons—indeed, it is a debatable point whether a certain degree of civilized hypocrisy be not indispensable for the maintenance of civiliza-

[1] Collected Papers, Vol. IV, p. 297.

tion, because the cultural adaptability so far attained by those living today would perhaps not prove adequate to the task. On the other hand, the maintenance of civilization even on so questionable a basis offers the prospect of each new generation achieving a farther-reaching transmutation of instinct, and becoming the pioneer of a higher form of civilization.' [1]

Thanks to the endless drill in man's loyalty to the abstractions of conventional ethics ever since the hour of his birth, he tends to exalt its dictates of conduct into immutable laws like those of the Medes and Persians. Instead of accepting his lapses in the field of conventional morality as the natural result of its artificial and preposterous demands, man has developed a sense of defeatism and morbid anxiety which have invariably interfered with his happiness, sanity and efficiency. Indeed, the code of conventional morality demands more sacrifice than it is worth. Its standard of conduct is neither directed by honesty nor instituted by wisdom.

When we turn to the field of the religious behaviour of mankind, we observe an equally disappointing situation. In spite of the highly organized institutions which have been erected to bolster the preposterous demands and claims of the various pseudo-religious systems, one cannot help noticing the subtle and seductive operation of certain primitive emotional forces in this type of behaviour which have proved refractory to man's rational control. Dispassionate studies of this field of human behaviour have served to expose the various totemistic beliefs and taboos, magical incantations and obsessional ritualistic observances which persist in it in an endless series of modern versions and which have to a large extent thrown man's intelligence out of function. Perhaps in no other field of human behaviour have morbid fear, infantile egocentricity, credulity, intolerance, illogicalities and intellectual dishonesty found such frequent and free expressions. 'Where questions of religion are concerned,' observes Freud, 'people are guilty of every possible kind of insincerity and intellectual misdemeanour.' [2] Psychoanalytic research has brought to light the neurotic character of the morbid religious attitude of man. It has shown that the pseudo-religious behaviour of man is the continuation of the obsessional neuroses of childhood and of the emotional irrationalities of his savage ancestors. A further line of evidence shows that certain modes of morbid religious behaviour are only disguised or symbolic ways through which certain individuals unconsciously gratify their suppressed wishes. Take the case of a sadistic individual who derives perverted pleasure from inflicting pain on others. There being few other avenues for the gratification of such pathological impulses without the

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[1] Vol. IV, pp. 299-300.

[2] Freud, S.: *The Future of an Illusion*, p. 56.

risk of social disapproval, such people often find a congenial atmosphere in the field of religious expression. The tension of their sadistic impulses finds relief in moral and religious denunciations, pious vituperations and scathing criticism of their neighbours. Since modern society hardly tolerates a cannibalistic form of human torture, at least under conditions of peace, one's sadistic impulses are as a rule restricted to such verbal assaults. Sadistic impulses often flourish under the guise of fanatic zeal. Likewise masochistic impulses very often find expression in the self-humiliating, self-torturing, ascetic ceremonials of pseudo-religious behaviour. Thanks to the social approval which attends the display of such behaviour, a large number of pathological manifestations in the field of religious behaviour remain unexposed. Another neurotic aspect of morbid religious behaviour is the other-worldly attitude of its devotees. This attitude will be found to be due, in a large number of cases, to the seductive influence of wishful thinking—the desire to escape from the stern realities of life. Such an individual, instead of redressing the wrongs of his society as he finds them here and now, clings fondly to certain illusory hopes which he expects to realize in the next world. This attitude of other-worldliness is not unlike certain forms of delusional insanity in which the patient ignores the world of real objects and lives in a dream-world of his own. Because of the uncritical attitude of society towards this mode of religious behaviour, a good deal of morbidity which masquerades under the garb of pious terminology, passes as a praiseworthy ideal of human conduct, and, in certain cases, is even a source of economic gain. Indeed the economic gains of certain religious institutions are so prolific that one is tempted to describe them in the words of E. B. Holt 'as strictly commercial enterprises as is a lottery, a soap factory or a pea-nut stand.'[1] This analysis of the religious behaviour of man could be profitably carried further, did the limits of time and space permit. But this brief discussion may serve to indicate that pseudo-religious behaviour, like the conventional ethics of our society is in urgent need of being rationally revised and adjusted to the real demands of the individual before humanity can hope to grow into rational and emotional maturity and, thereby, attain to health, sanity, efficiency and stability.

The efficacy with which the process of repression works in the life of the individual depends upon the subtle ways in which he is intimidated through the organized efforts of the various social institutions to whose influence he is constantly exposed. The repressive programme which begins in the earliest years of the growing infant makes use of all the horrors which are capable of frightening the child out of his wits. Parental disapproval,

[1] Holt, E. B.: 'The Whimsical Condition of Social Society and of Mankind', *American Philosophy Today and Tomorrow*, pp. 171–202.

the wrath of God, and the terrors of hell are a few examples out of a literally inexhaustible catalogue of institutional 'disciplines' which have been found efficacious in keeping the instinctual demands of the individual below the level of his conscious perception. Another result of this programme of repression is that these parental prohibitions and cultural taboos are gradually internalized in the shape of a conscience or super-ego whose chief function consists in plaguing individuals with self-reproach and a sense of guilt. This super-ego is now admittedly found to be the root-cause of a large number of mental disorders.

The internalized sense of social disapprobation and fear of consequent punishment, through the sheer force of the habitual docility of the individual, gradually degenerates into a mechanical or reflex function, so that the victim need have no conscious knowledge of its operation but may nevertheless be exposed to its painful consequences in the form of anxiety-neurosis or melancholia. Morbid fear and expectation of punishment is the invariable symptom of one's conflict with the super-ego. Very often the victim goes out of his way to punish himself. The various forms of the so-called accidental self-injuries or mutilations, in the last analysis, may be demonstrated to be the result of the unconscious sense of guilt and the demand for self-punishment. Indeed certain types of suicides and the event of recidivism could not be scientifically explained without the individual's unconscious sense of guilt and wish for self-castigation. In the light of such inexorable demands which it makes upon the already over-burdened individual the super-ego must be regarded as a neurotic stigma. A rational knowledge of its origin and nature would dispel the cloud of mystery which surrounds its compulsive character.

Two consequences of the conventional morality of our society appear to be most disastrous to the sanity and stability of man. (*a*) Repression which keeps the individual in a state of morbid ignorance with regard to the nature of his instinctual demands which in turn leads him to develop a state of smug and self-righteous satisfaction with our civilization. (*b*) The mental disorders or psychoneuroses which destroy one's happiness, sanity and efficiency through the operation of a rigid super-ego. This leads him to dissipate his creative ability in the various forms of neurotic manifestation. For, it must be clearly understood that repression of instinctual demands only renders one unconscious of their existence. In spite of the process of repression they carry on an underground existence and reveal themselves through certain bodily and psychical manifestations, generally known in the field of psychopathology as neurotic symptoms and disorders.

It must by now be abundantly clear how effectively the process of repression may dispel from the conscious knowledge of the individual the existence of his savage impulses. Let us

now turn to a brief discussion of its influence on the behaviour of young people within civilized society. One often hears of the perpetual restlessness and tension of the young men in our cultures. But if we lay aside the condemnatory attitude and view the situation objectively it will not be long before we discover the causal connection between this abnormal tension and the dictates of the conventional morality according to which they are expected to direct their lives. Viewed psychopathologically, anarchy, revolt and antisocial behaviour of every description and variety are only blood-letting devices calculated to afford relief to their abnormal emotional tension. The following statement of an eminent English writer is exceedingly significant:—

'You can re-write the history of all the great population movements in terms of the pressure of the young male surplus ...... Every community can be shown to be either sending out the plethora of its population as emigrants and settlers, or reducing it by warfare, or else suffering from acute social trouble, such social troubles as the words Russian Hooligans, Chinese Boxers, Moonlighters, Nazis, Fascists, revolutionary terrorists, gangsters, will call to mind. The young man surplus, if it is not consumed, is the main source of rebels, revolutionaries and disturbances of all kinds. Somehow that tension must find relief. The comparative social stability of the nineteenth century was largely due to emigration and the settlement of new lands. Now there are no more new lands open to immigration.'[1]

These words are all the more significant since they do not come from the pen of a professional psychologist. The writer has only recorded the fact of how young men in our culture are a perpetual menace to our social order. It is for us to correlate this fact with the extent of deprivation with which the instinctual demands of our young people are treated in our culture. Once again we have to thank the conventional ethics of our age for this sorry state of affairs. Its strategy of silence even where definite scientific knowledge concerning fundamental impulses of human nature is easily available, its deliberate distortion of such knowledge, its condemnatory attitude without any sympathetic insight into the state of the individual suffering from the strain of unsatisfied urges, the readiness with which it sacrifices the cause of truth and honesty by supporting falsehood and deceit in the service of its hoary conventions, its undisciplined idealism which has encouraged hypocrisy and self-complacent righteousness—all these have conspired to bring about the collapse of human intelligence and darken the destiny of mankind. It is high time that the exponents of this form of ethics should be made to realize the need of progressive

[1] Wells, H. G.: *The Fate of Homo Sapiens*, p. 42.

adaptation; and allow it to be tested by its results in a scientific spirit. The canons of right conduct must always take into account both the possibilities and the limitations of human nature.

The key to the social and political revolt of any country is to be found in the psychopathology of the young anarchist. Psychoanalytic study has demonstrated that oftener than not the leading social and political revolutionaries and anarchists have been recruited from the ranks of the victims of a deep unconscious hatred against parental authority. Their revolt against political authority was only a substitute reaction. Biographical studies of the leading anarchists often reveal significant familial situations which go to confirm the truth of this psychopathologic diagnosis. If all the facts concerning the parent-child relation from the biography of the great political revolutionaries and terrorists were to be made available to him, a psychoanalyst would undoubtedly be in a position to demonstrate that such individuals have been the victims of uncongenial family situations during their early childhood in which the male parent, unwittingly or otherwise, provoked the growing boy to harbour feelings of resentment and retaliation, feelings which he subsequently projects on to objects, which even in the remotest degree serve to remind him of the parental autocracy. Kings, government officials, teachers, priests have, it is known, often served as father surrogates who may bring out all the pent-up spite of the victim. Thus we see how an anarchist displaces his hatred for his father or father-substitutes on to social and political authority, and makes the world responsible for his unhappy childhood. A great deal of the antisocial behaviour of the individual is only the result of a displacement from the family to social maladjustment. At the bottom of many a political anarchy and unrest lies an emotional conflict between father and son. Generally the process is engineered by the unconscious forces of the victim's personality; and he often rationalizes his behaviour or simply treats it as an inexplicable mystery. It is only through the psychoanalytic technique that the ultimate cause of his trouble can be revealed to him.

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The limits of this paper do not permit the examination of other aspects of human behaviour which present an equally sad picture of the present state and future prospects of the human race. The trend of the current events seems to indicate that mankind is steadily heading towards self-destruction. The only way of escape consists in the intelligent use of scientific Psychology in effecting the mental and emotional re-adjustment which appears to be incumbent on human society today. A society which has developed the use of scientific Psychology is already on its way to sanity and stability.

But it might be objected that every individual is gifted with a reasonable degree of common sense which enables him to make the necessary adjustment in his life without the help of sientific Psychology; and that since he can always learn wisdom from the errors of his predecessors, he need not invoke the help of scientific Psychology.

The objection fails to estimate the dimensions of the task which confronts mankind today. It is not only the conscious aspect of human behaviour which stands in urgent need of being scientifically understood and re-adjusted. The vast and unchartered field of one's unconscious motivation must also be clearly cognized and rationally re-oriented. Common sense without the help of psychological knowledge and technique is unable to meet the requirements of this complicated task.

The plea for learning from the errors of the past is an ancient one. Few, however, have benefited from this. For, even here the dimensions of the task have never been clearly estimated by those who have consistently endorsed the wisdom of this plea. It involves not only the avoidance of a specific pattern of overt behaviour but a scientific understanding of the motives which invariably produce it. No useful purpose, for instance, will be served in holding the isolated actions of Nero or Napolean as warning signals to the coming generation. What is really needed is the re-interpretation of their life and actions in the light of dynamic psychiatry, before men can be in a position to learn from their errors. We must be able to correlate the disastrous events in the regime of the past rulers and leaders of humanity with their neurotic and psychotic afflictions before we can rationally understand them and effectively avoid their recurrence. The same spirit of research must be carried into the records of certain other aspects of human behaviour. The psychopathological nature of fanaticism, puritanism, autocratic parenthood and pedagogy, for example, must be equally understood. It will be only then that the present generation will have a chance of avoiding the mistakes of the past.

But when we remind ourselves of the extraordinary advance which our age has witnessed in the scientific technique of diagnosing the latent contents of the human mind, the plea for preferring the lead of common sense appears to be even more absurd. This advance is mainly due to the scientific labours of Freud and his collaborators in the field of psychopathology and child psychology. To quote that brilliant British writer, H. G. Wells, 'Our knowledge of our own motives and impulses and then of mass-thought and mass-action, has become beyond comparison more lucid and practical, thanks primarily to the initiative of Freud'. Whatever the nature and extent of one's disagreement with this great scientist, one can hardly afford to ignore the extraordinary penetration with which he has captured the fleeting unconscious wishes and fears in their microscopic

detail for an objective scientific study and control. It would be only a superficial student of human nature who would prefer vague surmises of common sense to this penetrating insight into human maladjustments made possible through this new psychological advance. It is a wholesome sign that some of the leading sociologists are now beginning to recognize the need of psychological knowledge in the programme of social and political re-adjustment. Thus Karl Mannheim writes: 'If we want to change the human personality as a whole and not just its external behaviour, we must penetrate beyond the external behaviour to that realm of consciousness in which the different meanings of external acts can only be comprehended by sympathetic understanding. Thus we must try to pass from accessible surface-indices to the more deep-lying background of psychological phenomena ...... The discovery of the unconscious makes it possible to penetrate into those hidden mechanisms through which psychological adjustment on the deeper levels of the self can be brought about.' [1] Without the aid of scientific Psychology any attempt at mental diagnosis and re-orientation will prove only a planless dissipation of energy.

Let us briefly review certain ways in which scientific Psychology can help human society to readjust itself so as to secure its future stability.

In the first place, since, according to our analysis, the present crisis in the affairs of mankind is mainly due to the irrational restraints which society has come to exercise on the instinctual demands of the individual, it is of fundamental importance to correct our attitude towards these demands. The prevalent dread of certain fundamental urges of human nature is mainly determined by animistic beliefs still lurking in the unconscious depths of our personality. The ideal of ascetic deprivation of these urges seems to be mainly determined by such unconscious animistic beliefs. Psychological re-orientation will involve the realization of the fact that deprivation of any satisfaction, in itself, has no value to human health and sanity. On the contrary, needless deprivation of a fundamental urge has been found to be more harmful than beneficial to the health and sanity of the individual. We freely concede that there are occasions when the individual has to forego at least a temporary gratification of his instinctual demands. But this must be done as a measure of prudence and in consistency with the principle of enlightened self-interest, rather than through a superstitious dread of these urges. Fear will invariably lead to the repression of these and the accumulation of hatred, hostility and anxiety with which human society is at the present moment seething. Even when the need for temporary depriva-

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Mannheim, K.: *Man and Society*, p. 217.

tion seems to be indicated on grounds of social adjustment, it is important to sidetrack the instinctual demand in question into some adequate channel of expression so that the temporary suspension of gratification may not pass into complete deprivation. We are reaping today a rich harvest of deep-seated fears, hatreds, jealousies and anxieties which have been accumulating in the human mind on account of the needless deprivations of instinctual satisfactions to which individuals have been blindly subjected since the day of their birth.

In the second place, psychoanalytic treatment must be made more generally available than it is at the present moment. Whereas it may not result in a hundred per cent cure, it will still go a long distance in relieving individual distress and in ensuring the sanity of mankind through psychological control. I grant that emotional health of society can only emerge slowly in this way. But when it does emerge, it will have a greater chance to stay.

We must, however, begin this work in the nursery. The psychological up-bringing of the child is the first step towards the mental health of the adult. The education of the child must be permeated through and through with the methods and principles of child psychology and mental hygiene. Unfortunately the current system of school education overemphasizes the purely intellectual nature of the child. The emotional aspect of his personality has not received the scientific attention which it demands. Consequently, one very often finds that a large number of individuals who pass through our existing educational mills, in spite of their intellectual development, remain emotionally immature. A great many maladjustments of the adult life are due to the continuance of emotional childhood beyond the normal period of its duration. We must deplore the lack of psychological insight of a large majority of those who bear the responsibility of educational leadership. This is further vitiated by the maladjusted teacher who is so overburdened with the heavy weight of his own emotional conflicts that one cannot reasonably expect him to guide his pupils along the lines of wholesome development of their personality. In the words of President Everett Dean Martin, '....... the teaching profession—with notable exceptions—tends to be filled with differential people, people who can trot in harness, conform to the system, take orders, and present controversial truths in an inoffensive manner. Teaching becomes a kind of trade similar in a way to other trades, with an average quality of workmanship and standardized quantity production of its object. People who all their professional lives must do just what they are told, commonly lose the habit—if ever it was of their organization—of judging the ultimate significance of that

which they are obliged to perform.'[1] A sound psychological training to prospective teachers is definitely indicated so that we may ensure the emotional health of the children entrusted to their care.

We must also urge the need of psychological clinics for children. For, in spite of the truth of the maxim that prevention is better than cure, and in spite of the supreme importance of adopting this maxim as the guiding principle at home and at school, there are nevertheless frequent occasions when even the most intelligent parents and teachers fail to know the neurotic-child-to-be when they see him. And even when they do know him it is very often at a time when the method of prevention is too tardy to operate effectively. There are several difficulties which prevent parents and teachers from clearly diagnosing and effectively treating the neurotic tendenies of their children. In the first place, a large number of neurotic symptoms of a child such as a pleasing docility, his speech difficulties, his eccentricities, his infantile ritualisms—instead of causing serious scientific concern about the child's normality, may please or amuse parents. In the second place, a large majority of those parents and teachers who do succeed in observing symptoms of neurotic behaviour in their children are liable to put them down to moral lapses and original sin. But by far the most urgent reason why we need psychological clinics for children is that owing to the peculiar nature of the tie which exists between parents and their children, there is always a limit beyond which no parent can guide a problem-child. May I add that not even an expert psychologist or a psychiatrist can help his own children beyond a certain limit. Take the case of a neurotic child. All that parents can do is to avoid those causes and conditions which may lead to the formation of neurosis in their children. This in itself is a colossal task. What they cannot do is to treat a neurosis *after* it has set in—particularly if *they* are the cause of it. There must be a psychical distance between the mentally sick child and the clinical expert, which distance, by the very nature of the case, is not possible between the parent and his child. Obviously, the only course open to parents, be they laymen or clinical experts, is to obtain clinical help from someone who has no peculiar ties of this nature with the patient in question.

Anna Freud, Melanie Klein, Margaret Lowenfeld, Susan Isaacs and others have brought an amazing psychoanalytic insight into the study of problem-children. Not only have they succeeded in accurately diagnosing the trouble of a large number of maladjusted children but have also brought health and

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[1] Martin, E. D.: 'Education', *Whither Mankind*, 1928, edited by Charles A. Beard, pp. 355 ff.

happiness into their lives. Their scientific work must be followed up by others in different parts of the world.

The help of psychological clinics is specially needed in the treatment of cases of juvenile delinquency. The blind use of penal methods is not only unscientific, it is definitely barbarous. To quote from the writings of one of the foremost British authorities in the field of juvenile delinquency: 'To whip a boy, to shut him up in a penal institution, because he has infringed the law, is like sending a patient, on the first appearance of fever, out under the open sky to cool his skin and save others from infection. It is as blind and unintelligent as the primitive treatment of malaria, in the days when the parasite of malaria was unlooked for, and the mosquito ignored. With moral disorder as with physical we must find and fight, not symptoms, but causes. Not before causes have been discovered, can cures be advised.'[1] Someone has rightly observed that the attitude of society to crime is essentially animistic. Few advocates of corporal punishment realize how their use of this kind of discipline may be actuated by the unconscious animistic motive of driving the devil or the evil spirit out of the offender. Not only do we physically attack the person of the juvenile offender with the object of driving his devil out of him but very often our own devil which we project on to him. The mental condition of offenders is a problem which calls for careful study. Experimental projects in this field clearly indicate that delinquents may be amenable to psychological treatment. It is important, therefore, to make the services of a medical psychologist available to juvenile delinquents.

It is, however, from the view-point of prevention of subsequent maladjustments that the period of childhood has its peculiar importance for us. According to the findings of psychologists in the field of delinquency and neurotic illness, the various kinds of antisocial and emotional maladjustments have their inception during the period of early childhood. Whether we are dealing with a notorious criminal or a neurotic individual, we are eventually led to consider the causal connection of their trouble with certain conditions in their early infancy. It follows from this that the incident of individual and social maladjustments to a large extent may be prevented through a psychologically enlightened home. If the home ignores the resources of scientific psychology in the wholesome up-bringing of its children, subsequent institutional care of the mentally ill and the delinquent will never be able to keep pace with the progress of mental disease and crime. For, in spite of therapeutic efforts and institutional care in individual cases, the incident of pathological manifestation at any given moment, will far outnumber the cases of cure so long as the conditions of pathology are

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[1] Burt, C.: *The Young Delinquent*, p. 5.

inherent in the very nature of the unfavourable home influences to which the child is constantly exposed. Under such circumstances increasingly more disorders will continually be produced than it would be possible for the curative agencies to tackle. The progress of disease will always keep steadily ahead of the therapeutic treatment. Total eradication of disease will thus remain absolutely outside the scope of human possibility.

It is, therefore, essential to realize the immense importance of parental education along the lines of scientific psychology as one of the most effective ways of ensuring the sanity of the coming generation. All actual and prospective parents must be educated in terms of the scientific facts and principles from the field of child psychology and mental hygiene. Nor should the value of the application of psychoanalysis to the profession of parenthood be ignored. There are subtle ways in which the personal neuroses of parents retard the normal growth of children. Certain causal factors in the psychology of problem-children very often may be traced to the emotional conflicts of parents. Psychological study of cases lends ample support to the statement that for every problem-child there is a problem-parent. Curiously enough, parenthood, one of the oldest human responsibilities, has not received the scientific consideration that it demands. A considerable amount of the scientific knowledge about the nature and development of the child is still a closed book for most parents. It must be clearly understood that the proper re-adjustment to life does not so much consist in what the scientists know, as in what the people apply.

It has been discovered invariably that a large number of neurotic and delinquent children come from unhappy homes. There may be a great many reasons to account for an unhappy home. But in the light of the findings of clinical psychology, we would emphasize the importance of a preliminary diagnosis of prospective marital companions in order to rule out at least one possible causal factor which is so likely to blight the life of the younger generation. A preliminary knowledge of the tastes and temperament of one's prospective marital companion is also essential for a harmonious home. Curiously enough whereas in the breeding of certain species of domestic animals greatest scientific care is exercised on the choice of a suitable mate in the interest of the health of the offspring, in the case of the human species this most important task is left to the caprice of the blind Cupid and his only too uncertain arrows. We also strongly endorse the opinion of Dr. Van De Velde according to whom little good for a healthy population is to be expected from marriages between those 'who are afflicted with mental disease, venereal disease, hypochondria, epilepsy, etc.'

Parents must, in particular, be enlightened about their obligation to their children in the field of sex-education. Through the irrational attitude and ignorance of their parents in this

field, many children grow into the belief that everything connected with sex is wrong and sinful. This in turn gives birth to a large number of personality disorders in their later life. Hysteria, anxiety neurosis, hypochondria, frigidity and impotence have often been observed to be the direct outcome of a morbid attitude towards sex which an individual acquired during his childhood. The conspiracy of silence with which parents meet children's questions regarding sexual knowledge, is the most prolific source of the sexual morbidity which prevails in modern society. A large number of sexual maladjustments which go to poison the marital life of individuals also have their roots in the subtle lies with which parents had attempted to discourage accurate knowledge on the part of their children. Curiously enough, whereas our children are encouraged to be up-to-date in the field of science and art, they are kept perilously ignorant of this fundamental urge of their nature. In theory our educational experts admit readily enough that fearlessness and freedom are good for a child, and yet where sexual enlightenment is concerned they impose slavery and terror.

Sex education must be given in an atmosphere of scientific freedom and in a dispassionate attitude. It must be based on the most up-to-date findings in the field of sex psychology. Medical psychology has brought to light the fact that sex urge has its roots in the period of early childhood; and that a large number of neurotic disorders of the grown-up individuals within our culture are in the last analysis actual fixations at, or regressions to, certain infantile forms of sexual manifestations. By debarring our children from a healthy sex education, we expose them to all sorts of maladjustments. Whatever the amount of controversy on the subject, only a short-sighted parent will disregard Freud's warning that mental and personality disorders are, in the last analysis, traceable to sexual factors. In the light of these findings it follows that sex education must be given at an early age so as to ensure the healthy attitude of the coming generation.

It must, however, be noted that sexual education must be suited to the problems peculiar to the specific strategic level of one's psycho-sexual development. Sex education, therefore, cannot be a fixed, uniform course of knowledge irrespective of the specific needs of the growing individual. It must be a carefully graded scientific information suited to the psycho-sexual development of the individual concerned.

The basic task of psychological re-education involves a complete emancipation of the child from all the irrational fears with which he is surrounded. In this connection it must be recognized that if religion is to have a wholesome influence on the personality of the child, it must be purged of all those irrational threats which are likely to turn him into a coward and a hypocrite. It is mainly against this form of religion that

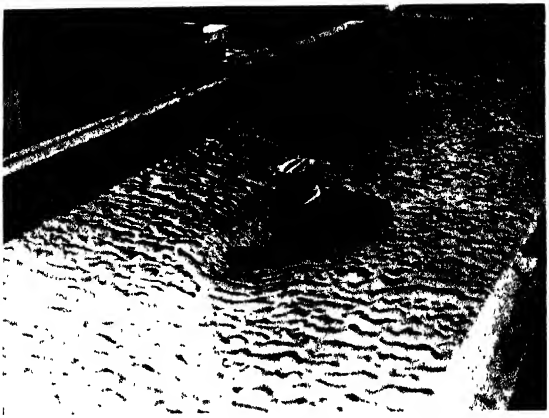
Freud's criticism may be interpreted as constituting a warning. The fundamental distinction between religion and pseudo-religion is one of attitude. Whereas the former consists in an attitude of courage, confidence and unselfish love, the latter involves an attitude of fear and infantile egocentricity. Nothing is more damaging to the sanity of the growing child than the influence of pseudo-religion. We strongly deprecate the condemnatory, negativistic attitude of the unenlightened priest who instead of infusing confidence and courage into the lives of individuals makes them the pitiable victims of abject terror and guilt. There is in the life-history of the child nothing so morbid as an exaggerated sense of guilt. This often leads to self-deceit and internal conflict, alien to the nature of the wholesome child, and forces morbid thinking and feeling which scar even the happiest disposition. Today mental hygiene considers this feeling of guilt in childhood as one of the most damaging happenings of early life, from which the child must be guarded as much as possible by those who minister to his needs.

Another way in which psychology will be found to have supreme value for the task of social re-orientation is the application of its scientific findings in the field of vocational selection. We do not refer to the application of vocational guidance and selection tests whose value is necessarily limited by their being largely confined to the exploration of the *conscious* aspects of one's vocational selection. In the light of the recent findings of psychoanalysis, the choice of an individual's vocation is very often determined by his unconscious motives. Dr. Wilhelm Stekel, for instance, has demonstrated how one's vocational choice may be determined by any of the five main motives working in the unconscious depths of his mental life. These are: identification with the father, hostility against the father, desire to sublimate, erotic and criminal impulses, defence or a protection against unconscious tendencies, and lastly, an unconscious sexual motive. These unconscious motives very often drive an individual to a choice of a profession in which, in spite of his spasmodic manifestations of enthusiasm, he often relapses into a sense of morbidity and inefficiency. In order to illustrate the various types within this classification, one may consider the case of the boisterous 'rough-neck' who may choose to become the manager of big electric works, a sadist who may choose the career of a surgeon, 'Jack the Ripper' who may develop into a gynecologist, an incendiary into a fireman, a foot fetishist who may choose the trade of a cobbler or may practice pedicure, and a man who is afraid of his criminal impulses may develop into a clamouring clergyman or a denouncing demagogue.

'But why not?' one may argue, 'Is not the individual, whatever his original unconscious motive, all the saner for having somehow transformed his dangerous impulses into a

useful and socially acceptable vocation?' Decidedly not, we reply,—at least not so long as he is unconscious of the existence of these motives which carry on an underground activity within the subterranean depths of his personality. Not until he is enabled to have a psychological penetration into them can he be considered safe against their seductive influence. Like the delayed action explosives these dangerous motives bide their time; and may go off at any moment. Until he is liberated and re-oriented through psychological insight such an individual continues to be a social liability—a perpetual menace to the stability of the human race. We conclude that until psychoanalysis is pressed into the service of vocational guidance and selection, the most important aspect of this field will remain sadly neglected.

We have endeavoured to demonstrate from the various lines of evidence set forth in this paper that mankind has reached a critical point in its life-history where two alternatives irrevocably confront it: It must either seriously set about the task of emotional re-education and mental re-orientation towards problems of human life and experience or it must face the alternative of self-extermination. The second alternative is not the product of morbid fear. It is based on scientific evidence from the authentic records of the fate of certain species within the animal kingdom. Geological research has unfolded for us an amazing variety of fossils which show the ruthless extinction of whole species of animals who once dominated the earth but who in the course of evolution repeatedly failed to readjust themselves to the changing conditions of their environment. When we contemplate the obliteration of these mighty creatures, we tremble with deep concern for the future of mankind. For until a complete re-orientation is achieved within a short space of time, man bids fair to extinguish himself. The choice is irrevocable. There are only two alternatives: It is either re-education of man or the catastrophy of his cataclysmic extinction. This presents to Psychology its present task.



1410. Scour around a bridge pier model
Looking upstream.

Separation of the nappe from the weir faces

2255. Showing separation of the nappe at side
(Note the silk threads in the centre and at side.)

SECTION OF ENGINEERING

President:—C. C. Inglis, C.I.E., B.A., B.A.I., M.Inst.C.E., M.Am.Soc.C.E.

Presidential Address

(*Delivered on Jan. 7, 1941*)

HYDRODYNAMIC MODELS AS AN AID TO ENGINEERING SKILL

Introduction

There are few subjects concerning which so much confusion of thought exists as about the correct rôle of hydrodynamic models.

There is a marked tendency for Engineers either to hold that models give highly reliable results, or that they are untrustworthy, and must be viewed with grave suspicion.

The main reason for this confusion is due to hydrodynamic models being of several markedly different types, some giving highly accurate results, while others produce results which diverge widely from what occurs in the prototype; so that river conditions must first be translated to model equivalents and model results translated back to river equivalents.

The aim of this address is to clarify this question; not by mere statements, but by explaining the reasons why some experiments are highly reliable and have become little more than routine practice; while others depend almost entirely on field knowledge and correct diagnosis of field conditions.

Classification

In a previous Paper,[1] models were divided into 8 types; but it is now proposed to simplify the question by reducing the classification to 4 main types:

Type I. Geometrically similar models which give geometrically similar results.

,, II. Geometrically similar models which do not give geometrically similar results.

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[1] 'The use of models for elucidating flow problems based on experience gained in carrying out model experiments, at the Hydrodynamic Research Station' by C. C. Inglis, *Proceedings of the National Institute of Sciences of India*, 1938.

Type III. Models with a mobile bed, in which 'flow pattern' is the dominant factor.
" IV. Vertically-exaggerated models of rivers:
(*a*) rigid;
(*b*) semi-rigid;
(*c*) mobile.

Type I

Geometrically similar models which give similar results.

The reputation achieved by model experimentation has been built up mainly on models of Type I. In this category may be classed Rigid Models in which changes in energy relations between velocity and pressure is the chief factor, necessitating a similar Froude No. (V^2/gd) in model and prototype. This covers experiments to determine:

(*a*) coefficients of discharge,
(*b*) standing wave relations,

but fairly accurate results are also obtained as regards

(*c*) lines of flow at offtakes, and
(*d*) scour downstream of falls.

A host of successful experiments of this type will be found in the Annual and other Reports of the Poona Station and other Stations throughout the world; the results being highly accurate provided the model is not too small and roughness in the model is correctly adjusted or divergences allowed for.

A few examples of this type of model will be cited from recent annual reports:

I(a). (i) *Coefficient of discharge of Nira Left Bank Canal Head Regulator* [1]

Examples of Type I.

In this case the problem was to increase the discharge of an existing regulator, consisting of 7 spans of 4 ft., by 50%. By bell-mouthing upstream, and constructing an expansion downstream, the coefficient in the formula $Q = VA = AC\sqrt{2gh}$ was increased from 0·81 to 1·93, making it possible to increase the discharge with the same head 2·3 times, where

Q = discharge in cusecs,
V = mean velocity,
g = acceleration due to gravity, and
h = head = difference of W.L.s upstream and downstream.

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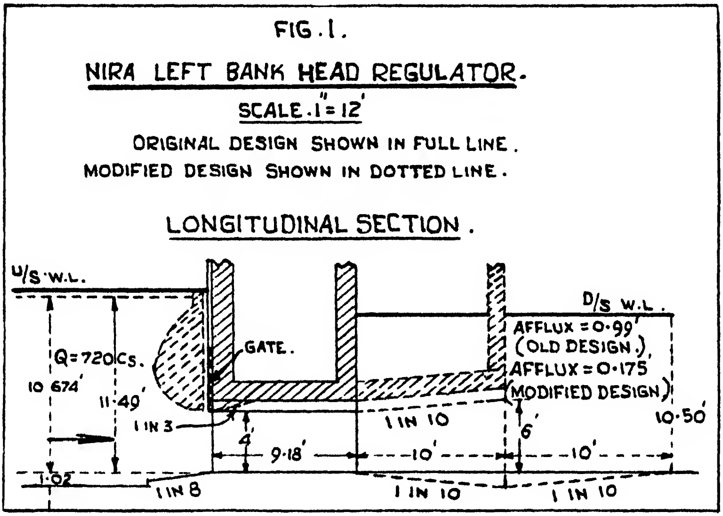
[1] Bombay P.W.D. Technical Paper No. 54: 'Note on experiments with a model of the Head Sluices of the Nira Left Bank Canal.'

Figure 1 shows the original design (in full lines) and the modified design (in dotted lines).

The coefficients worked out from the model agree approximately with those obtained subsequently in the Canal.



I(a). (ii) *Determination of the variable coefficient of the* 10,569 *cusecs Tando Mastikhan Fall on the Rohri Canal, Sind* [1]

These experiments with a geometrically similar model have shown that the coefficient decreased with increase of depth and discharge due to impact losses at pier noses which necessarily increased with depth. The discharge formula of the Tando Mastikhan Fall in Sind was found to be

$$Q = C_1 (B - K\,n\,D)\,D^{1.5}$$

where K = coefficient of contraction.
= 0·083 in Tando Mastikhan Fall.
n = number of piers = 9 in Tando Mastikhan Fall.
B = Waterway = 100 ft. do.
D = D_1 (Depth of water upstream over sill of flume) + $Va^2/50$.
C = a coefficient.

The accuracy of the results obtained in the model has been borne out by observations in the Canal.

[1] Annual Report of the Central Irrigation and Hydrodynamic Research Station, 1939-40.

I(b). Standing wave relations of the Tando Mastikhan Fall in Sind[1]

The standing wave relations in the Canal agree almost exactly with the model results.

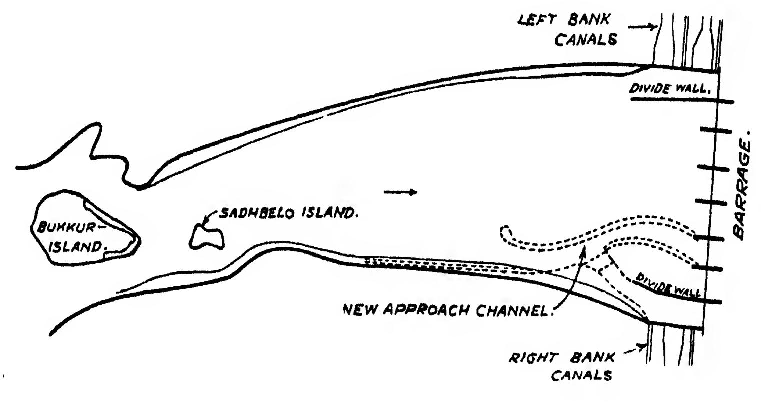
I(c). Design for entrance to right pocket from new approach channel at Sukkur[2]

Figure 2 shows plan of the Indus above the Sukkur Barrage with the new approach channel, designed to control the quantity of silt entering the Right Bank Canals.

FIG. 2.

PLAN SHOWING DESIGN OF NEW APPROACH CHANNEL, ALONG RIGHT BANK, TO EXCLUDE SILT FROM RIGHT BANK CANALS AT SUKKUR. (SHOWN DOTTED)

SCALE. 2 INCHES = 1 MILE.



The Right Bank Canals, in particular the North-Western Canal, draw excessive bed silt. As a result of model experiments

[1] Bombay P.W.D. Technical Paper No. 44: 'Dissipation of energy below falls.'

(NOTE.—Instructions for design in Tech. Paper 44 superseded by those given in the Irrigation Research Division, Poona, Annual Report for 1934-35.)

[2] Annual Report of C.I. and H.R. Station, 1937-38 (pp. 26 and 27); 1938-39 (pp. 4 to 10); and 1939-40.

carried out 11 years ago [1] it was predicted that a silt bank would form along the right bank, and that the right bank canals would then silt. In the floods of 1936, the River carried an exceptionally heavy charge of bed silt, and the predicted sand bank formed along the right bank and heavy silting occurred in the North-West and Rice Canals. Various alternative methods of reducing the quantity of silt entering these canals were tested and the optimum design found was that of a curved approach channel 5,000 ft. long—shown in figure 2. This investigation presented many difficulties. Six different models with various scale ratios were used to determine the effect of different factors. To determine the best design of offtake from the Approach Channel to the pocket supplying water to the Right Bank Canals, a geometrically-similar, part-width, model was used and later the same model was used with increased depth to give a vertical exaggeration of 2 in the model as against a vertical exaggeration of 7 in the river model. This model showed that the width of entry could be made 35% less than shown by the river model with V.E. = 7.

I(d). Scour below flumed falls [2]

Reasons for scour below falls:

(1) Excess energy gives rise to eddies and surging flow.

(2) Instability of flow, due to expansion, causes 'heaving'.

(3) Too sharp divergences cause jetting, which sets up rotary flow and eddies.

- (i) The cheapest and best way to destroy excess energy in a glacis fall is to construct a baffle at such a level and height, and in such a position, as to destroy a maximum of energy.
- (ii) A deflector at the end of a pavement redistributes velocities and prevents scour downstream by causing a roller with a horizontal axis to form.
- (iii) Permissible divergence decreases slightly with increase of discharge.
- (iv) Diverging vanes in continuation of piers fan out flow successfully if correctly designed.

The Tando Mastikhan Fall was constructed with side expansion too sharp, viz. 1 in 5 against 1 in 10 required. Vanes to fan out the flow were therefore added. The fall, with these modifications, is operating very efficiently and bears out all the conclusions drawn from the model. Subsequent experiments have shown that a high fluming ratio necessitates longer

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[1] Bombay P.W.D. Technical Paper Nos. 45, 46 and 52.

[2] Bombay P.W.D. Technical Paper No. 44, and also Annual Report of the Central Irrigation and H.R. Station for 1939-40.

expansions to obtain suitable downstream conditions, and that falls should be designed to work satisfactorily even though 25% retrogression occurs; because some designs fail under such conditions.

A border-line case between Classes I and II is a siphon spillway. It comes under Class I for fully primed coefficients; but gives different results for priming depths.[1]

Type II

Under Type II may be cited some recent experiments carried out at Poona:—

Geometrically similar models which do not give similar results.

(i) Coefficients of High-coefficient Weirs.[2]

(ii) Slab movement in submersible bridges.[3]

(i) In the case of High-coefficient Weirs, in which the curvature of the profile of the Weir is sharper than the path which filaments of water would follow if discharging freely into air, the coefficient of discharge in the formula $q = c\ D^{1 \cdot 5}$, where q = discharge per foot run and D = upstream depth over weir, increases both with depth of water over the weir and scale. The former is due to the fact that as Q increases, the natural path of flow under aerated conditions diverges more and more from the curvature of the weir and hence, so long as the water adheres to the weir profile, a reduction of pressure occurs; and as

$$p/w + V^2/2g + Z = \text{constant}$$

for a filament (Bernoulli's theorem) the velocity is correspondingly increased and also the discharge.

An increase in scale also causes an increase in scalar discharge; because whereas pressure is constant when the water discharges freely into air, the reduction of pressure increases with scale, and hence the velocity and Q also increase.

It was not possible to estimate the discharge in the prototype, theoretically, and so a series of models of different scales were constructed and results extrapolated to give conditions in the prototype as regards pressure and discharge.[4]

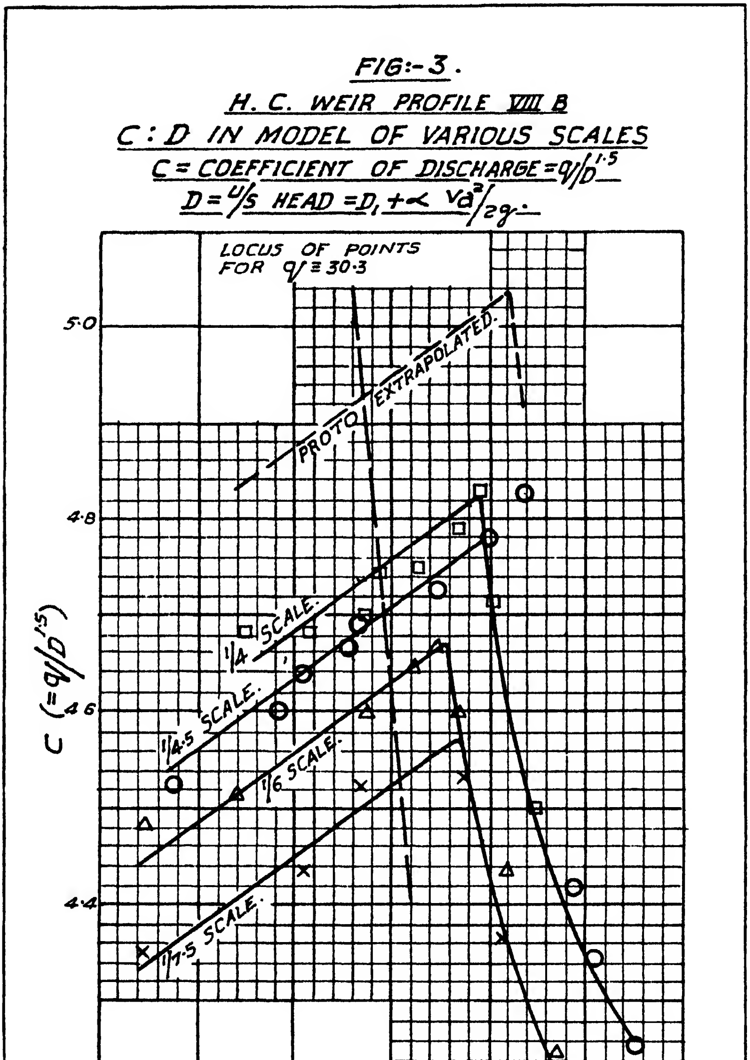
Figure 3 shows the coefficients obtained in models with scales: 1/4, 1/4·5, 1/6 and 1/7·5 of the prototype. From this it will be seen that the larger the scale, the higher the coefficient.

[1] Annual Report of the Central Irrigation and Hydrodynamic Research Station for 1939-40.

[2] Annual Report of the Central Irrigation and Hydrodynamic Research Station for 1937-38, pp. 39 to 44 and 1939-40.

[3] Annual Report of the Central Irrigation and Hydrodynamic Research Station for 1938-39, pp. 31 to 37; and Annual Report, 1939-40.

[4] Annual Report of the Central Irrigation and Hydrodynamic Research Station for 1937-38, pp. 39 to 44 and 1939-40.



When these coefficients were extrapolated, the conclusion arrived at was that the coefficient in the prototype with $D = 3{\cdot}35$ and $q = 30{\cdot}3$ cusecs would be 4·93 compared with 4·75, 4·7, 4·63 and 4·53 in the various scale models.

In this particular case, as a result of constructing a new 200 cusec channel, we are now in a better position to check up the accuracy of the conclusions hitherto arrived at by extrapolation from small models to full scale; but even this has presented difficulties; because whereas the weir at Bhandardara is 650 ft. long, it is only 4 ft. in the model; so that the effect of the side boundaries, which is negligible in the prototype, is considerable in the full scale model; so has to be allowed for.

The method adopted after small scale trials was to draw the flow into the 4 ft. channel containing the model, through a bell-mouth from a wider channel. This had the effect of regularizing velocities across the 4 ft. channel.

It was necessary, however, to place the model sufficiently far downstream of the bell-mouth for the flow approaching the weir to be sensibly parallel. As a result of this, slight boundary layer effect was present. A further difficulty arose at the weir itself due to retardation of the high velocity flow at the sides. The effect of this was partially corrected by providing a very small degree of expansion in the side-walls, but the effect on the pressures remained, causing slight inward flow at the crest, relieving the negative pressures and so reducing the discharge coefficient. This inward flow can be clearly seen in Photo No. 2255 (preceding the Address) in which threads, fixed on the weir, show distorted lines of flow.

Figure 4 shows the coefficients of discharge in the formula $V = C\sqrt{2g\,D}$ plotted against depths D in the full scale model.

It will be noticed that the coefficient instead of rising to a clear-cut maximum as in figure 3, rises on a curve, and before reaching its natural maximum, falls to meet the rapidly falling line at $C = 4{\cdot}70$. Dotted lines show the rising and falling curves extrapolated. These meet at $C = 4{\cdot}9$ with $D = 3{\cdot}35$ ft., as compared with 4·93 extrapolated from small scale models (*vide* figure 3); but whereas by that method the maximum value of C rose to 5·03 with $D = 4{\cdot}10$, this has not been attained in the part-width, full-scale, model, due to side effect.

(ii) *Slab movement in submersible bridges* [1]

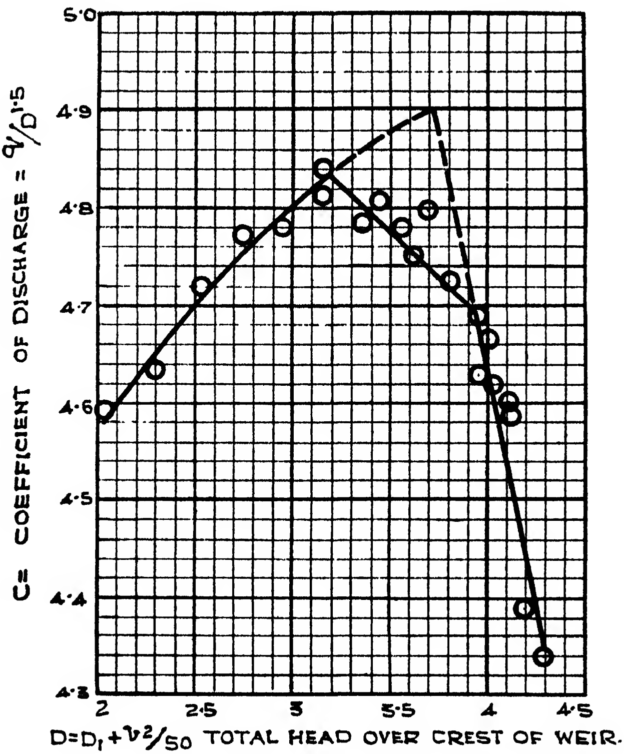
In this series of experiments, though impact effects were accurately reproduced, yet slabs of specific gravity equal to that in the prototype did not move in the model, though this had happened in rivers in the Central Provinces. Indeed the model slabs did not move in a 1/12 model with $V = 2{\cdot}5$ ft./sec. (equivalent to 8·5 ft./sec. in the river) even though the weight of the slab was reduced from 46 lbs. to 31 lbs., corresponding

[1] Annual Report of the Central Irrigation and Hydrodynamic Research Station for 1938-39, pp. 31 to 35.

weights in water being 27 lbs. and 12 lbs. respectively; so that the relative weight in water was only 44% of the equivalent weight in the prototype.

FIG. 4.

SHOWING C:D CURVE FOR FULL SCALE MODEL OF H.C. WEIR 4 FEET WIDE.



This investigation showed that the washing away of unanchored bridge slabs was due to vibrations set up by rapid changes of pressure induced as a result of the high Reynold's No. in the river; and it was shown that the larger the model the higher the specific gravity of the slab which was just washed away with the same relative discharge.

The model showed that movement was so gradual as to be scarcely visible except over appreciable periods of time, and was probably discontinuous; but eventually the slab moved downstream on its pier supports until about half the slab overhung, when it tipped up and was carried downstream. In this case, extrapolation could not be resorted to in order to determine the weight of prototype slab which would just not move; because the scatter in different observations in the model was of the same order of magnitude as the effect to be determined. This did not matter from the practical standpoint; because the Station was asked how to stop this occurring and the obvious solution was to anchor the slabs or provide stops to prevent the slabs moving downstream on their pier supports.[1]

Type III

Mobile models in which flow pattern is dominant factor.

A good example of a model with a mobile bed in which 'flow pattern' is the dominant factor is the conditions of flow which exist round a bridge pier constructed in erodible sand.[2]

It is shown in the 1938-39 Report that scour at pier noses is due to the oncoming water, which is deflected by the pier, diving downwards towards the upstream toe of the pier before sweeping outwards on either side of the pier—see photo 1410 at the beginning of this Address. This action is due to the 'flow pattern' and is scarcely at all affected by the upstream bed level, which, in turn, is determined by the sand of the river bed; so that, whereas the depth of actual bed upstream of the pier is $\propto q^{\cdot 71}$, the depth of scour at the toe of the pier $= 1{\cdot}7b^{1/4}\, q_c^{1/2}$,

where q = maximum discharge per ft. width,
d_s = scour depth at nose of piers,
b = width of pier, and
q_c = discharge per ft. width some distance upstream of pier.

The latest experiments show, however, that when a pier is protected by stone, the depth upstream has an effect on the discharge which causes failure, the stone failing with a smaller discharge when the bed level is higher—i.e. when the bed material is coarse.

Although scour at a pier, and to a lesser extent at spurs, can be estimated roughly from formulae and applied to specific cases of rivers, yet complications arise in river models which are naturally vertically exaggerated. This will be dealt with later, as it falls under both Types III and IV.

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[1] Annual Report of the Central Irrigation and Hydrodynamic Research Station for 1938-39, pp. 31 to 35 and 1939-40.

[2] *Ibid.*, pp. 39–41 and 1939-40.

TYPE IV

Vertically-exaggerated models of rivers:

(*a*) Rigid,
(*b*) semi-rigid,
(*c*) mobile channels.

IV(a). Rigid vertically-exaggerated models

In such cases, the usual practice is to fix a suitable vertical-exaggeration, estimate the mean roughness required, and then verify slopes for known discharges. If the slope is in error, the roughness is altered until it becomes satisfactory. This is a slow process; because changes made in one part of the model affect other parts. Then again, though the model may give satisfactory results with one discharge, it may give unsatisfactory results with a larger or smaller discharge; and a uniform roughening will not give correct results. A large amount of data and much patient 'trial and error' work is therefore necessary which, experience in America shows, may have to be spread over a period as long as two years. After such verification, it is assumed that correct levels will be obtained for conditions outside the verified range—as for instance in a flood of greater magnitude than previously observed or when different slopes and local intensities of flow occur, due to peak floods in tributary streams reaching the main stream at different times from those of previous recorded floods. Such models can undoubtedly give most valuable information as regards flood levels, lines of flow, and points where violent action will occur under such conditions; but the model, being rigid, cannot give direct information about scour, which must be inferred by the experimenter, nor will the flow for such conditions be correct; because in nature, heavy scour would cause marked changes in conditions.

Rigid models have been used to a large extent at the U.S. Waterways Experiment Station at Vicksburg in connection with tidal model studies. In many of these, coal dust and other still lighter materials have been injected to indicate the movement of sediment and the amount of sediment likely to deposit in various positions, marked out on the bed of the model by white-bordered squares, has been measured by sucking the deposited material through a vacuum cleaner type of machine, the material then being separated by a machine resembling a cream separator. The difficulties to be overcome in such models are very great, and the data required for successful verification enormous, it being considered desirable to have detailed data for a period of 5 years.

A rigid model of a 20 mile length of the Hooghly above Calcutta has been constructed at Poona to determine lines of flow and points where bed action is severe under various

conditions of river and tidal flow. It is the intention to use this information subsequently, in semi-rigid or mobile part-models, to investigate the specific bank-scour problem, using much larger discharges.

IV(b). Semi-rigid

In semi-rigid models the sides, and in some cases large parts of the bed, are held. This, by making it practicable to enforce a vertical exaggeration in excess of what is natural, makes it possible, while retaining the same Froude Number as in the prototype, to increase the slope, and hence the silt charge.

This makes it possible to reproduce similarity much more accurately than is possible in a fully-mobile model and so simplifies interpretation. On the other hand, it imposes conditions throughout the length of the model, and the model cannot scour its banks, which are rigid, nor change its course; and if, as is generally the case in India, the question we desire to investigate is 'future changes of river course and the secondary effects of such changes', we must, when using models in which the sides are held, predict the changes and the rate of those changes, to enable us to determine the secondary effects which will result from these changes.

An excellent example of a case in which this was done is the Rangoon model.[1]

In that case the model was bounded by a curved wall dividing the assumed tidal flow affecting the model problem, from the tidal flow to the East; and the right bank of the River was cut away from time to time at a rate assumed by the experimenter, based on judgment. Working on these two assumptions, it was found that while the Port was not threatened by eventual extinction, it was evident that some limitation on the draught of vessels using the Port would be inevitable unless rectification of the approaches was carried out by artificial means—a prediction which, it is understood, has been fulfilled. The point I wish to emphasize here is that the correct result obtained in this model was due to the skill of the experimenter in making correct assumptions, and had he made incorrect assumptions he would have got wrong results.

IV(c). Mobile channels

In this section it is intended to work up from the simple to the complex. The simplest case of a mobile channel is one in which the discharge and silt charge are constant.

[1] Institute of Civil Engineers, Paper No. 5100: 'Investigation of outer approach channels to the Port of Rangoon by means of a tidal model' by Oscar Elsdon.

Lindley in 1919 put forward the original theory that 'the dimensions, width, depth and gradient of a channel to carry a given supply, loaded with a given silt charge were all fixed by nature'.[1]

Nine years later, Gerald Lacey produced a series of formulae which fixed gradient and dimensions of channels.[2]

Recently, Lacey has set forth his theory as developed up to July 1939.[3]

His formulae, re-stated in terms of the two independent variables Q and f—discharge and silt factor—are as below:

$$\begin{aligned} P &= 2{\cdot}667\ Q^{1/2} \\ R &= 0{\cdot}472\ (Q/f)^{1/3} \\ V &= 1{\cdot}1547\sqrt{fR} = 0{\cdot}7937\ Q^{1/6}f^{1/3} \\ S &= 0{\cdot}000542\ f^{5/3}/Q^{1/6} \end{aligned}$$

where P = wetted perimeter; R = hydraulic mean depth; V = velocity and S = slope.

These may be compared with the corresponding formulae subsequently worked out by Dr. Bose of the Punjab Irrigation Research Institute in 1937, which were evolved by statistical methods from a mass of regime channel data collected over a period of 5 years in the Punjab:[4]

$$\begin{aligned} P &= 2{\cdot}8\ Q^{1/2} \\ R &= 0{\cdot}47\ Q^{1/3} \\ V &= 1{\cdot}12\ R^{1/2} = {\cdot}767\ Q^{1/6} \\ S &= 0{\cdot}00209\ m^{\cdot 86}/Q^{\cdot 21} \end{aligned}$$

where m = Mean diameter of silt.

Accepting the Lacey and Bose formulae as being very approximately correct for regime conditions, we find that whereas P, the wetted perimeter, varies as $Q^{1/2}$; R, the hydraulic mean depth, varies as $Q^{1/3}$, and hence R/P, the shape, varies as $1/Q^{1/6}$; which means, in model terminology, that vertical exaggeration (= hydraulic depth ÷ hydraulic width) varies inversely as the 1/6th power of the discharge, the channel shape being relatively deeper in small than large channels. It will be noted that in the Lacey slope formulae, the slope for the same silt factor also varies inversely as $Q^{1/6}$; and hence, according to the Lacey formulae, slope exaggeration is equal to vertical exaggeration for the same silt in model and prototype; but, whereas the silt

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[1] 'Regime Channels' published in *Proc. Punjab Engineering Congress*, Vol. VII, 1919.

[2] 'Stable channels in alluvium' by Gerald Lacey, *Proc. Inst. C.E.*, Vol. 229, 1929-30.

[3] 'Regime channels in incoherent alluvium,' Central Board of Irrigation, Publication No. 20 of 1940.

[4] Punjab Irrigation Research Institute Reports for the year ending April 1937 and April 1938.

factor 'f' enters 'vertical exaggeration' (which refers essentially to the cross-section of a stream) in the form

$$V.E. = R/P \propto (Q/f)^{1/3} \div Q^{1/2}, \text{ or } 1/f^{1/3}Q^{1/6},$$

slope exaggeration enters in the form $S.E. = f^{5/3}/Q^{1/6}$; that is to say, whereas a coarser silt increases the $S.E.$, it decreases the $V.E.$ and the ratio $S.E./V.E.$ varies as $f^{5/3+1/3} \propto f^2$. From the sensitiveness of this relation it will be clear how important it is to choose correct silt conditions in a model.

For these and other reasons, channels can be designed much more accurately by the use of formulae than by model studies, and hence models are not required, nor would they be useful for designing ordinary channels, though they are very useful when the problem is to ascertain why unnatural conditions arise in the vicinity of masonry works, bends, or changes of material of sides or bed.

Lacey Limiting Velocity

Inherent in the Lacey formulae there is a limiting velocity. Lacey has assumed that the natural shape of a silt-bearing channel in incoherent alluvium is an ellipse, and hence the limiting section is a semi-circle, so

$$P/R = 2\pi = 6{\cdot}283$$

and as

$$\begin{aligned} P^2 &= (2{\cdot}67)^2 Q = 7{\cdot}12\, PRV \\ P/R &= 7{\cdot}12\, V = 6{\cdot}283 \\ \text{or } V_{\text{lim}} &= 0{\cdot}882 \text{ ft. per second.} \end{aligned}$$

If, however, $P = 2{\cdot}8\sqrt{Q}$ (Dr. Bose's formulae, derived from Punjab data) then $P/R = 7{\cdot}84\,V$ or $V_{\text{lim}} = 0{\cdot}8$; and if $P = 3{\cdot}2\sqrt{Q}$, our Station formula for a certain range of discharge and types of silt, $V_{\text{lim}} = 0{\cdot}62$. While it must be admitted that the assumption that a semi-circle is the limiting shape of a channel is, at best, only an approximation; yet, if even approximately correct, it leads to the conclusion that in natural silt-bearing channels carrying small discharges, a change of law must occur when the discharge reaches a certain low discharge. This change of law would be sudden according to the Lacey formulae, but is more likely to be a gradual transition in practice, taking into consideration the known gradual decrease of silt movement with reduction of discharge. Eventually silt movement must cease and the law must then be different. It was found at Poona in 1937, on plotting available data, that silt charge varied approximately as $(V - V_{\text{rt}})$, where V is the actual velocity and V_{rt} is what we have called the 'regime threshold velocity', which, for practical purposes, is the same as

'competent velocity', a term used in America for the velocity at which silt movement just commences.[1]

It has been found that the velocity at which silt movement ceases in shallow channels is little affected by depth; but, unlike in the Lacey theory, it depends on grain size, varying approximately as $V_{rt} \propto m^{1/3}$.

With the sands normally used at the Poona Station, V_{rt} varies between 0·7 to 1·0 ft./sec.

From this, it follows that silt movement, always relatively much less in a natural mobile model than in its prototype, will start in a river with a relatively low discharge and will continue until the discharge again finally falls to this same low value; whereas in a model, with a flood velocity of say 1·25 ft./sec., silt movement will not begin until the discharge is equivalent to about half the flood discharge:

As long ago as 1929, A. H. Gibson in his Report on the Severn,[2] concluded that the best results were obtained with a silt which was 20% finer than in the prototype and the use of a somewhat finer silt in models is almost certainly desirable.

That this is likely to be so, follows from Lacey's latest theory[3]: that for a given degree of agitation the silt charge varies inversely as the terminal velocity of silt falling through water (V_s), which in turn varies approximately as m (where m, the mean diameter of bed silt particles, is of the order 0·2 to 0·5 mm.), the relation being $m = 0{\cdot}0645\ V_s + 0{\cdot}042$.

This theory was based on an analysis of a paper by Dr. C. M. White entitled 'The influence of transported solids upon Rivers'.[4]

The correctness of the theory has already been shown by the Poona Station both for very heavy silt charges[5] and normal silt charges.[6] Though this relation enables us to increase the silt charge by reducing the grade, it has little effect on the velocity at which silt movement begins and ends; so does not eliminate our main difficulty.

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[1] Studies in Engineering, University of Iowa, Bulletin 5: 'The transportation of detritus by flowing water—I.' By F. Theodore Mavis Chitty Ho and Yun-Cheng Tu.

[2] 'Construction and Operation of Severn Tidal Model' by Prof. A. H. Gibson—Paper written for Economic Advisory Council, Severn Barrage Committee.

[3] Note on Dr. White's theory of 'Silt Transport' by G. Lacey, dated 13th December 1939.

[4] Read by Dr. White (City and Guilds, London) to the Potomological Section of the International Union of Geodesy and Geophysics at Washington, D.C., U.S.A., in September 1939.

[5] C.I. and H.R. Station Interim Basic Note No. 50, dated July 1940: 'Rate of deposition of silt as governed by silt charge and terminal velocity.'

[6] C.I. and H.R. Station, Supplementary Basic Note No. 50, on the same subject—with natural silt charge.

Effect of a Limiting Velocity

The effect of this limitation is not important in those relations in which action takes place at maximum discharge, so does not appreciably vitiate results as regards limits of embayment, as shown in the Hardinge Bridge experiments.[1] In this, it was shown that had free embayment been allowed to occur upstream of the Right Guide Bank of the Hardinge Bridge no damage would have resulted; whereas by constructing the Damukdia Guide Bank across the natural line of flow, natural embayment had been prevented, which had led to an increase of action at the Right Guide Bank, and consequently had been an important factor contributing to its failure.

In a large proportion of river problems, however, the scour which occurs during falling floods is a very important factor in determining flow conditions the following year, and this is not reproduced correctly in natural models.

The alternatives to meet this situation are to depend mainly on experience and judgment or else to distort the model scales to increase silt movement with low discharges.

Methods to reduce effect of Limitation of Silt Movement

Two methods have been followed at Poona to increase silt movement in the model for conditions corresponding with low river discharges:

(*a*) low discharges have been scaled up, and
(*b*) slope has been exaggerated.

To deal with this question adequately would require a separate paper. Suffice it to say here, that in general, the first method gives valuable information over part of the model but does not give correct results over the whole of the model. An example of this is the 1/300 scale model of the Sukkur Barrage from which we have obtained similarity of bed contours and flow along the right bank, which was the problem we were investigating; but conditions on the left bank were not correctly reproduced which, in this particular experiment, did not matter.

Reduced Silt Movement in Models

Although it is a digression, it seems advisable, at this point, to touch on the question of 'silt deposition'.

In a river, by far the greater part of the silt in motion is normally in suspension, whereas in models the proportion of

[1] Bombay P.W.D. Technical Paper No. 56 entitled 'Report on experiments with models in connection with the protection of the Hardinge Bridge on the Eastern Bengal Railway'.

silt in suspension is relatively small. For this reason, not merely is the silt movement much less in the model; but the silt which deposits in the river—namely fine suspended silt—forms a relatively small part of the model silt charge. The reproduction of full natural silting in the model is therefore well-nigh impossible even if the time scale be based on silt charge—i.e. on $(V - V_{rt})$—which would lead to the time scale being greatly increased as the silt charge decreased with smaller discharges.

This is not quite so bad as it sounds; because scour starts later in the model and is relatively less than in the river; in other words, just as silt movement in the model is relatively much less, so also is the amount of annual scouring and silting. Should this fact be overlooked and the model bed be laid according to cold weather conditions in the river, scour pits at the noses of groynes or obstructions would contain more silt than would be natural in the model; and this excess, when scoured, would produce unnatural sand banks in the model.

An extreme example of reduced silt movement in a model is afforded by the 1/300 Sukkur Barrage model in which, if the model is regulated as at the Barrage, silt movement does not begin till the discharge exceeds half the normal maximum flood discharge.

Slope Exaggeration

Coming now to the second method of inducing early scour, i.e. slope exaggeration: This necessitates a smaller vertical exaggeration and hence, in effect, distorts the model. This method may be very useful in a short model provided entry conditions are correctly imposed, but is not suitable for long models. Before dealing with the relative merits of long and short models the question of distortion requires further consideration.

Effect of Exaggeration of Banks and Rigid Structures

In most Stations it is the practice to exaggerate bank slopes and rigid structure according to the depth exaggeration scale; because otherwise they would occupy a disproportionate width of the model, and the deeper the scour, the greater would be the projection of the toe of a groyne or other rigid structure. This does not, however, produce correct results in the model; because owing to the 'flow pattern' being approximately similar in the model and prototype, while the depth is relatively much greater in the model, the width of bed action is relatively much greater in the model—as already explained in para 10—; and where, as in the case of scour at the nose of the new approach channel at Sukkur, the scour pit is very deep relative to the

width of the channel, the width of the scour pit in the model, the slopes of which are determined, as in the river, by the angle of repose of the material, extends right across the approach channel.

In addition to this, (but in this case reducing the error) the depth scale of the scour pit is different from the scale of the river part of the model, depending—as explained in para 10—on a different law, and as steep banks exceed the angle of repose of all except rigid materials, natural bank scour is precluded. In practice, therefore, the choice lies between rigid, steep, sides, and mobile, and hence relatively flat, slopes which take up much too great a width of the model.

In some models, and in some parts of most models, bank action is comparatively unimportant; but in many cases this is a very important factor and the limitations can only be partly overcome by the use of large-scale part-models.

Throw-off

'Throw-off,' by which is meant the angle of deflection of the filaments, is also distorted in vertically-exaggerated models, and to get approximate similarity of 'throw-off', the slope of the rigid structure has to be considerably less vertical at its upper end than according to that due to the vertical scale-exaggeration of the model.

Longitudinal Distortion

Finally, we come to longitudinal distortion: Vertical exaggeration is essentially a latitudinal exaggeration, just as slope exaggeration is essentially a longitudinal exaggeration; but in model studies, even when the slope exaggeration is increased by tilting the model, to increase slope and velocity, the longitudinal scale is almost universally made the same as the latitudinal scale. This is done in order to prevent distortion in plan. This means that both rigid and non-rigid parts of all vertically-exaggerated models are distorted: That is to say, they are foreshortened longitudinally in the ratio of the vertical exaggeration.

In extreme cases this would lead to sub-critical conditions in the river being converted into hyper-critical velocities in the model; but more generally it leads to distortion due to the length in which changes have to take place being foreshortened. Thus the length in which new lines of flow or eddy-patterns have to become established in the model as a result of changes of section or roughness is inadequate in the model to establish the change before a further alteration in the angle of flow or roughness occurs.

Two good examples of this are flow from the twin gorges at Sukkur [1] and the groynes in the Jumna at Delhi.[2] In the former, the gorge is foreshortened 7½ times, affecting both lines of flow and eddy pattern of the water leaving the gorge, while in the latter case the groynes were seven times closer together relative to depth than in the river.

Long and Short Mobile Models

The advantage of a long model is that curvature of flow and silt distribution are more natural, and so the river is more free to swing or change its course. Meander condition,[3] on which the solution of a large proportion of river problems ultimately depends, are also more accurately reproduced. On the other hand, less distortion of slope and discharge is permissible to obtain increased silt movement; and cost of collecting data, verification, and carrying out experiments is very much greater. In addition, the likelihood of omitting some important substratum—such as layers of clay, kankar, etc.—is proportionately increased; and finally, no matter how long the model may be, entry conditions, on which changes in a meandering river largely depend, and to a smaller extent, exit conditions, must be correctly imposed.

In a relatively short river model, much greater control is possible and much more silt can be kept in motion than in a longer model; but the results also depend to a much greater extent on the accuracy of the conditions imposed at entry—i.e. the distribution of silt and curvature of flow of the water. To impose these correctly is always difficult, necessitating a deep understanding of field conditions, which must be accurately diagnosed and completely visualized before their effects can be correctly imposed. Obviously those who can diagnose upstream conditions can also foresee, with equal accuracy, what the model portion of the river will do; hence the skilled experimenter knows very approximately what result the model should give when he is designing it and before he carries out experiments. The main function of river models, therefore, is to check up results with the experimenter's ideas, improve on them, and then fill in details. It is only in the simplest cases, which scarcely require model verification, that a single model will suffice. In most cases, as for instance, experiments in connection with controlling silt entry into the Right Bank Canals above the

[1] Annual Report of C.I. and H.R. Station, 1939-40.

[2] *Ibid.*

[3] Programme of Proceedings, 11th Annual Report of the Central Board of Irrigation, India, 1940, 'Factors controlling meandering' by C. C. Inglis, pp. 94–109.

Sukkur Barrage,[1] we have had to use several different models—6 in that case—varying from geometrical similarity to vertical exaggeration of 7½.

Conclusions regarding Scope and Limitations of Mobile Models

The impression I may have created is that river models cannot be expected to give useful information. That, emphatically, is not my view; but any idea that all you have to do is to construct a vertically-exaggerated scale-model of a river and that it will give the correct answer is nonsense.

I will quote a few cases which will clarify this point:

(1) 'We were asked to advise on how to control the main channe along the left bank of the Sarda River above Banbassa Weir. In the course of the early experiments, though the model did not indicate it, the conviction grew that the river would swing and burst through the central island. Subsequently, a very close inspection of the river confirmed this belief, which was not shared by the local officers. This was of importance; because, in the event of this happening, the work required would then be modified. In spite of a stone bank being built to prevent such a spill channel forming and to direct flow into a central, existing, channel, the stone was swept aside and a spill channel formed which carried 30% of the river discharge in the first year.'

(2) 'We were asked to design a fall required to check very severe scour which had been occurring in a nala.

The data supplied, and design proposed, showed a steep gradient and hypercritical velocities. Previous experiments carried out at another Station, with a lined, geometrically-similar model, had given similar flow conditions to those shown in the designs.

Before experiments were started at Poona, it was concluded that such conditions could not persist and that either the banks would scour, causing intermittent shooting flow and standing waves, or else the bed would scour, flattening the slope until subcritical velocities resulted. The practical effect of this was that a depth of 14 ft. of water was to be expected above the proposed fall, against 6 ft. assumed in the design and, by modifying the design it was shown to be possible to reduce velocities downstream to sub-critical, eliminating the necessity for lining the downstream channel.

Although subsequent model experiments with an unlined channel confirmed these predictions, it was impossible to reproduce similarity of silt conditions or scour of banks; so the results depended largely on the conditions imposed, i.e. on the judgment of the experimenter.'

(3) 'We were asked to make proposals to protect a Railway Bridge, the left abutment of which was being heavily attacked.

The plan did not seem to indicate any cause for such scour, so enquiries were made as to whether any cut-off had occurred in the river. This proved to be the case.

It appears that this cut-off can be closed, an alternative solution which will be much cheaper and more satisfactory than fighting conditions resulting from the river having shortened its course by one mile.'

(4) 'Up to 1923, the Jumna River was flowing along the right bank past the Pumping Station. Subsequently, the river began to move across to the left bank opposite the Pumping Station, necessitating the excavation

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[1] Annual Report of C.I. and H.R. Station, 1939-40.

and continuous dredging of a channel from the left bank to the Pumping Station.

The original remedy we proposed[1] was to remove the upper and lower of the 3 spurs built on the left bank and to build a short spur just below the Pumping Station on the right bank, to draw the river across to that bank.

The efficacy of the design was shown in our model with the equivalent of 100,000 cusecs flowing in the river, which brought the river across in one flood season; but the resulting channel was relatively considerably wider than the Jumna cold weather channel. On subsequent inspection it was considered that as a result of stone crate pitching done along the river face opposite, and downstream of, the Pumping Station, combined with dredging, the river was likely to change across without removing the upper of the three groynes; so developments were awaited. The following year the river moved across to the Pumping Station, as predicted, though the flood discharge was only 31,000 cusecs, or less than 1/3rd that with which the change occurred in the model—i.e. with a discharge which was so low that very little scour could occur with the equivalent discharge in the model.'

(5) 'It has been found impossible to reproduce the changes which occur from year to year in our Ganges model, despite it being a very large model over 500 ft. long. In general, scour has occurred too quickly and silting much too slowly; and consequently the Damukdia channel has reopened too quickly.

If the period of the experiments were reduced it would give the rate of scour of Damukdia channel more correctly but would make other parts of the model still more wrong. Certain it is that the rate of opening of the Damukdia channel was predicted more accurately from experience and judgment than can be indicated by a model.'

At Poona, we have been doing various scale experiments, for several years, with mobile models—to evaluate divergences resulting from various disturbing factors—in order to see how these effects can best be minimized by modifying slope scales, discharge scales, silt charge, and vertical exaggeration away from natural conditions.

These investigations have given us a clear understanding of why certain modifications which we have been carrying out have been successful; but they have not, and cannot, entirely eliminate the inherent divergences nor resolve the numerous complex factors. Natural mobile models do not, in fact, give similarity; but only results which are capable of being translated approximately from river to model and back to terms of river conditions: and results necessarily diverge more and more as the period of the experiment increases.

Frequently it is stated that river results have been verified in a model and have been found to be closely correct. We all, however, seem to relay the model every year according to the latest survey instead of carrying on year after year! The reason given for this is that the flood differed from what was assumed; but the real reason is that only qualitative similarity has been achieved.

[1] C.I. and H.R. Station Annual Reports for 1937-38, pp. 65 to 1938-39, pp. 14 to 16; 1939-40.

Also, as our object is to predict what will happen hereafter—not as a rule for a year or two, but for several years ahead—if the divergences in a single year render it advisable to relay; this, in itself, is an admission of the limitation.

Our experience of verification is that there is rarely enough river data available to make verification satisfactory, except as a rough qualitative check, and even if there were, it would, at best, be a very slow and tedious process; because every appreciable change in one factor affects all the others.

Conclusion

I cannot do better than repeat what I wrote in my Symposium Paper of 1938 for the National Institute of Sciences of India, on 'The use of models for elucidating flow problems':

'The general conclusion is that in competent hands, a very wide range of experiments with large models gives results of high qualitative accuracy and may also give quantitative accuracy; but, in the case of river models, the data available is generally meagre, and though the gaps in data can be filled to a large extent by an officer with wide field experience, so that a model can be made to reproduce what has previously occurred in the prototype under known conditions of discharge and silt charge, the problems which generally have to be tackled are of immediate urgency, the discharge data being inadequate and the silt charge data nil, and we are asked "what will happen if nothing is done?" or "what should be done to prevent further damage?".

'Satisfactory answers depend to a marked extent on an intimate knowledge of the engineering side of the problems under consideration combined with a flair for diagnosis.'

Mobile river models are in fact a valuable aid to engineering skill, which, however, they can never replace.

Although this Address expresses my own viewpoint, yet much of it is based on work done by the Station staff at Poona and I am especially indebted in this respect to Mr. A. R. Thomas, Deputy Director, and Rao Sahib D. V. Joglekar.